MULTIPLE MODEL ADAPTIVE ESTIMATION

AND CONTROL REDISTRIBUTION PERFORMANCE

ON THE VISTA F-16

DURING PARTIAL ACTUATOR IMPAIRMENTS

VOLUME III

DTIC QUALITY INSPECTED 3

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DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

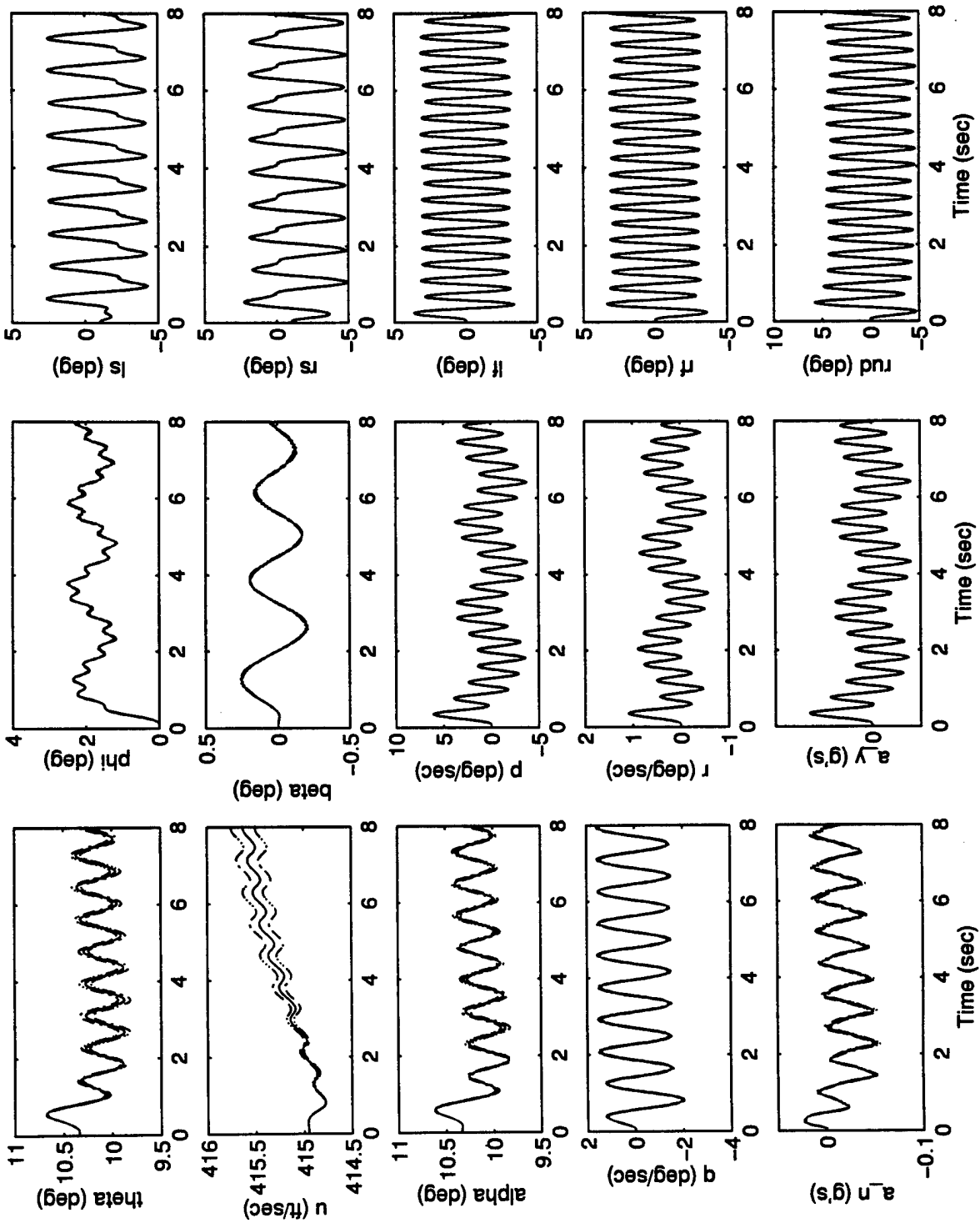Wright-Patterson Air Force Base, Ohio

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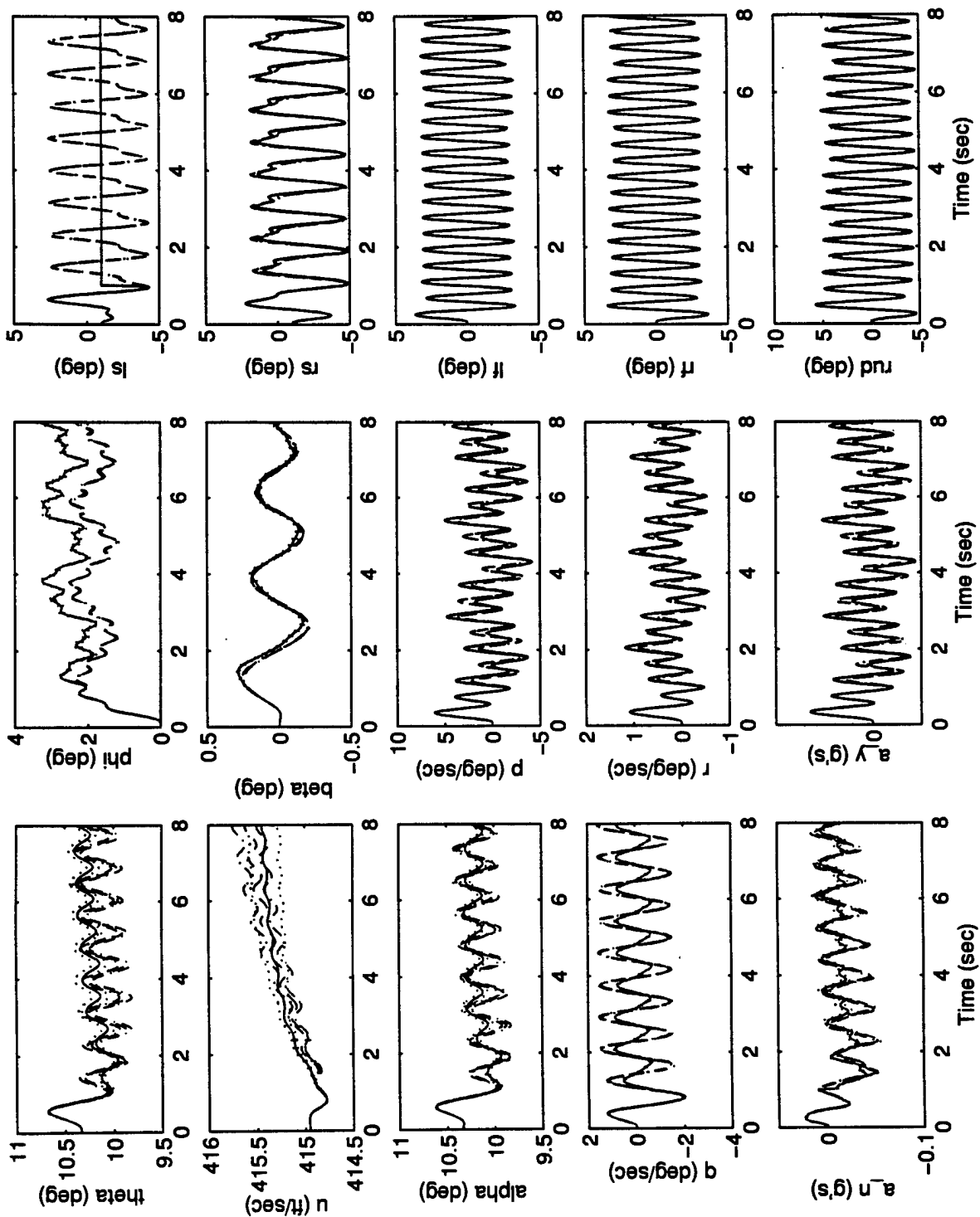
'OFF', Dither 'ON', No Maneuvers

This appendix contains the State Plots for cases of single, total (100%) actuator impairments without aircraft maneuvering or Control Reconfiguration (Redistribution), but with control dithering (Sections 4.5 and 4.11.1 with Appendix A.1). Each page of State Plots in this appendix contains three columns of five plots and corresponds to one impairment condition, or test point. The first column shows the aircraft longitudinal states and normal acceleration (a_n). Column two shows lateral-directional states and lateral acceleration (a_y). The third column, of most interest to us, displays actuator positions (not commands). Two actual time histories, the result of a 10 Monte Carlo simulation run of each impairment condition, are plotted on each of the 15 subplots. The first time history, a "dashed / dashed-dotted" trace, represents the "mean ± one standard deviation" of the *fully functional* aircraft response. The second time history is a "solid line / dotted" trace and represents the response of the *impaired* aircraft at the given impairment condition.
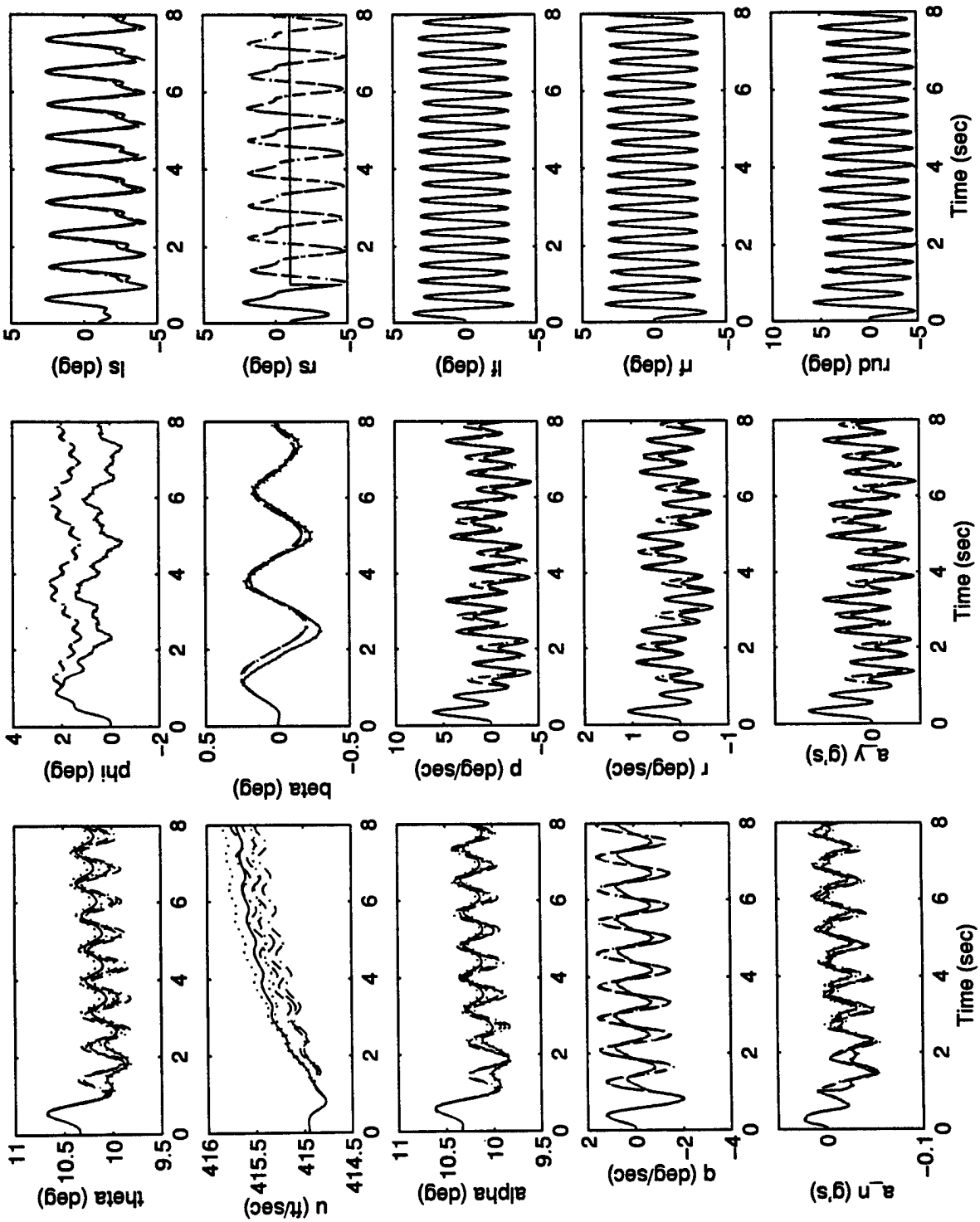
FULLY FUNCTIONAL AIRCRAFT

LEFT STABILATOR FAILURE

RIGHT STABILATOR FAILURE

LEFT FLAPERON FAILURE

RIGHT FLAPERON FAILURE

RUDDER FAILURE

Appendix E.2: State Plots for Single Total Actuator Impairments ($\varepsilon = 0$), Control Redistribution

'ON', Dither 'ON', No Maneuvers

This appendix contains the State Plots for cases of single, total (100%) actuator impairments without aircraft maneuvering, but with Control Reconfiguration (Redistribution) and with control dithering (Sections 4.5 and 4.11.2 with Appendix A.2). Each page of State Plots in this appendix contains three columns of five plots and corresponds to one impairment condition, or test point. The first column shows the aircraft longitudinal states and normal acceleration (a_n). Column two shows lateral-directional states and lateral acceleration (a_y). The third column, of most interest to us, displays actuator positions (not commands). Two actual time histories, the result of a 10 Monte Carlo simulation run of each impairment condition, are plotted on each of the 15 subplots. The first time history, a "dashed / dashed-dotted" trace, represents the "mean ± one standard deviation" of the *fully functional* aircraft response. The second time history is a "solid line / dotted" trace and represents the response of the *impaired* aircraft at the given impairment condition.
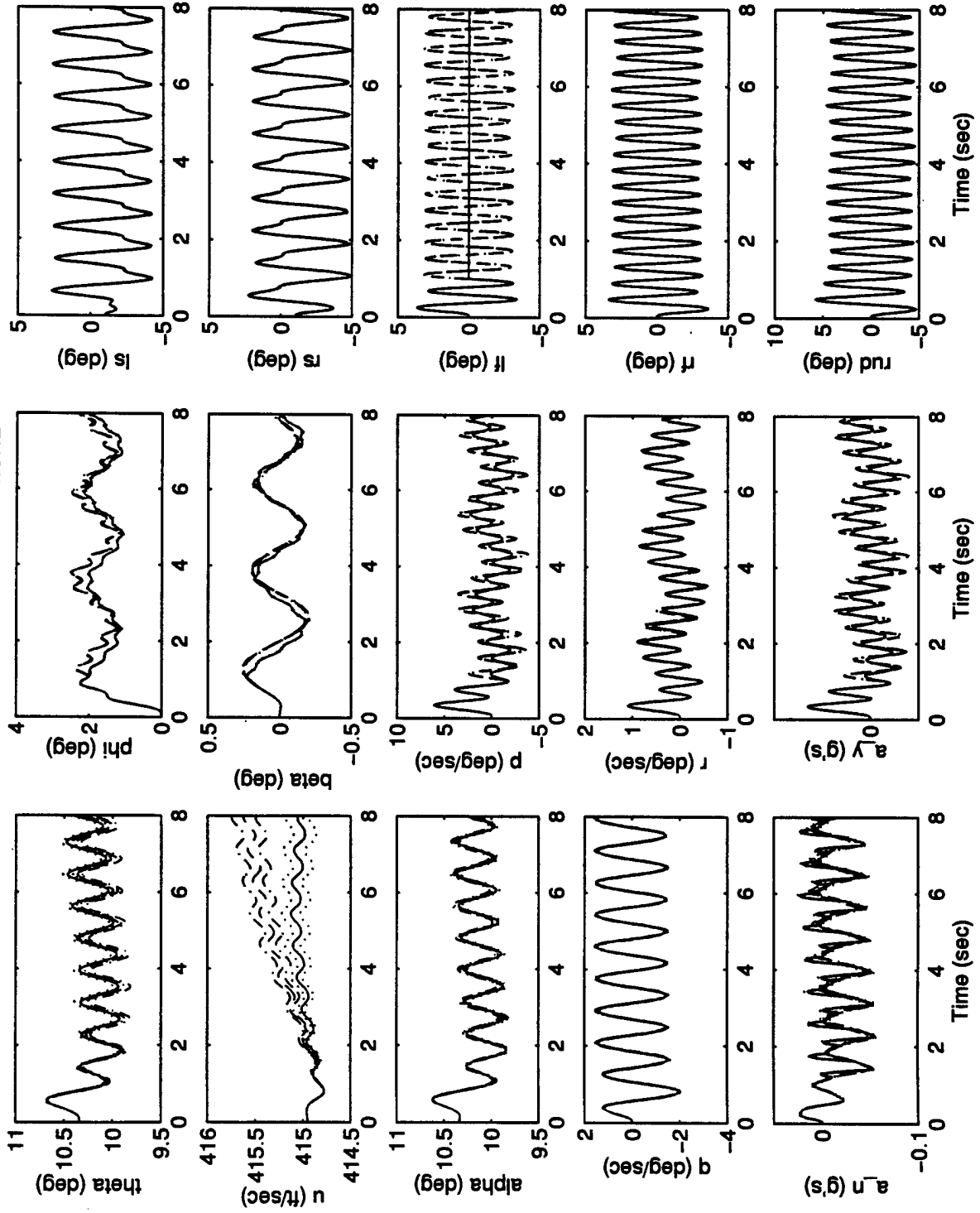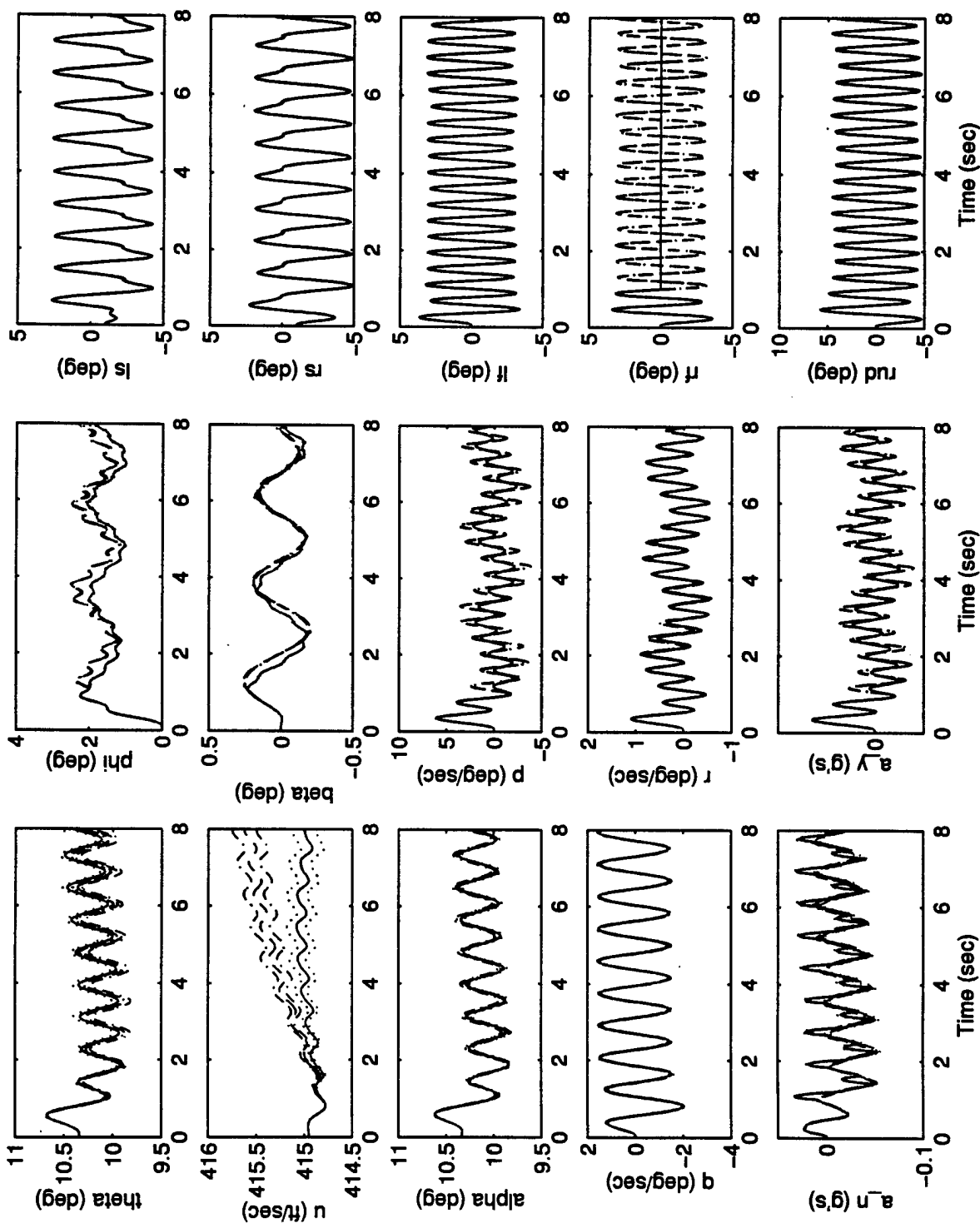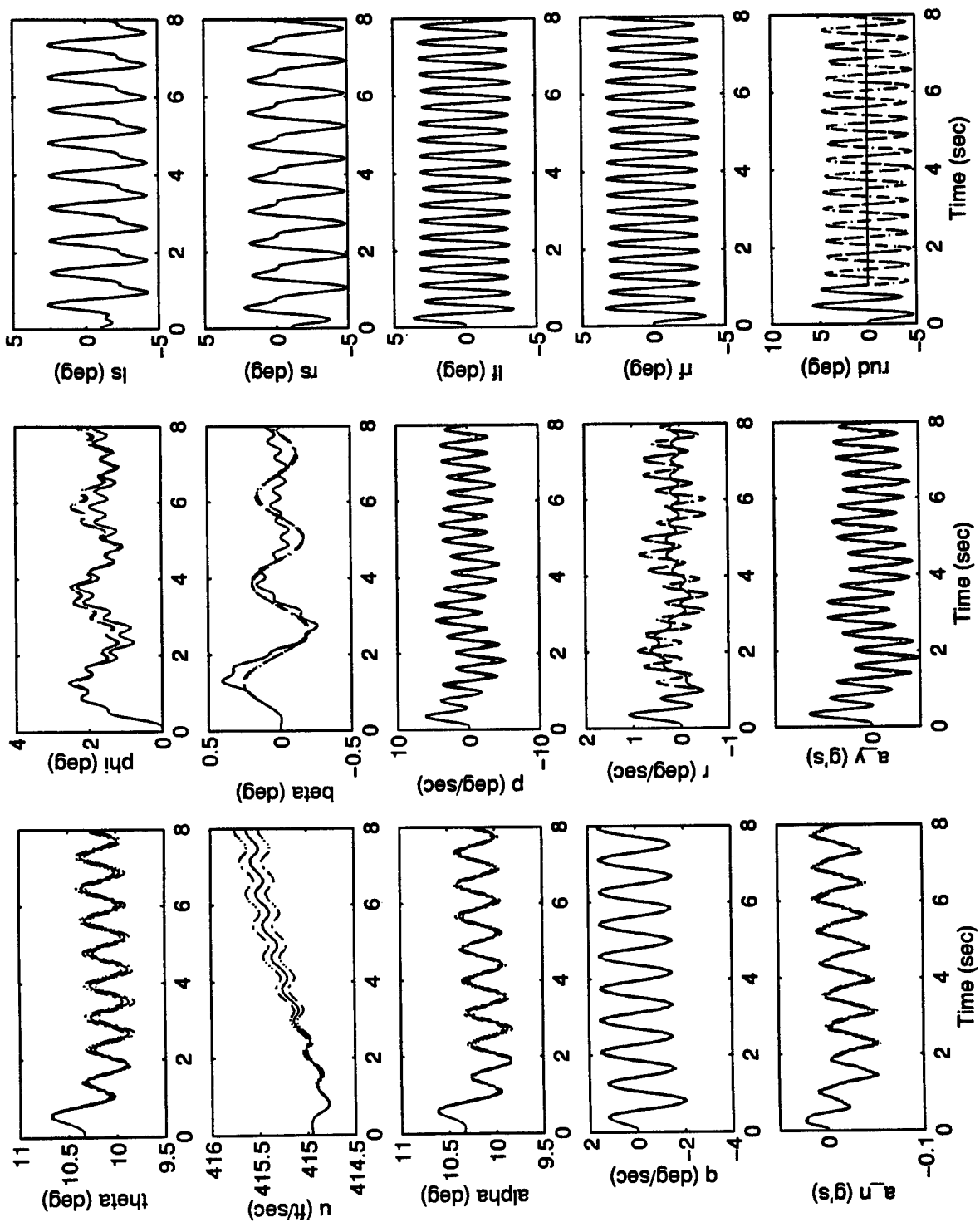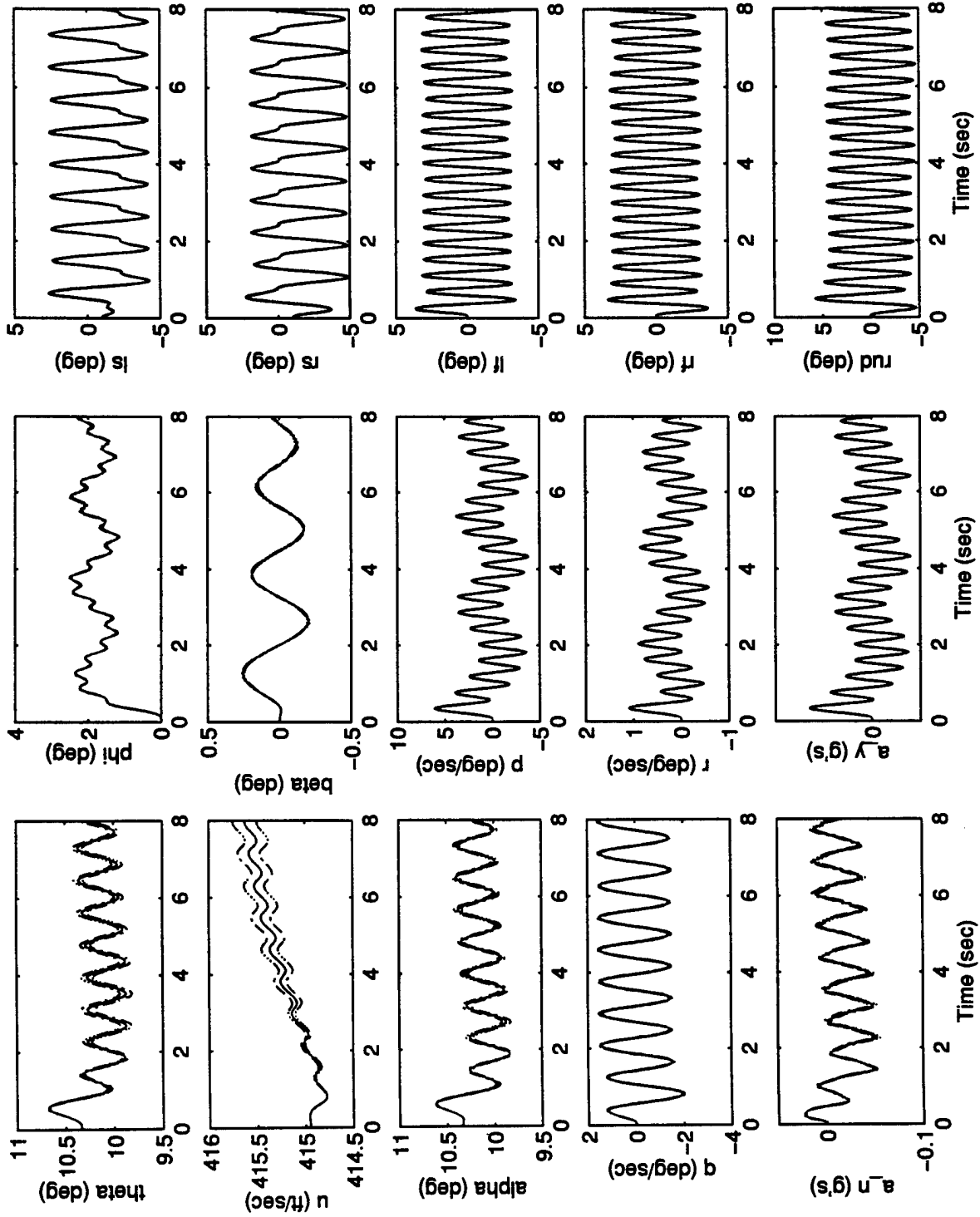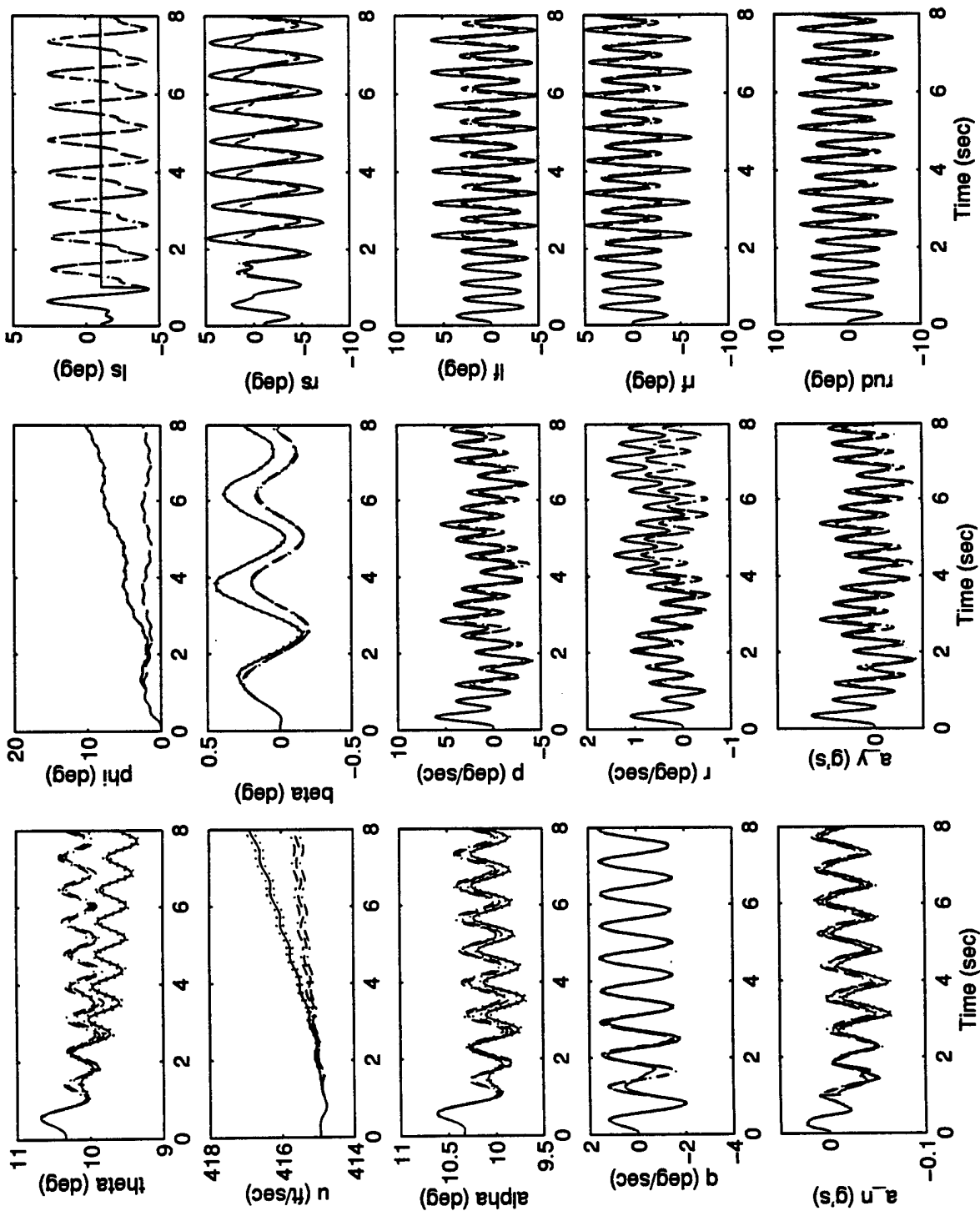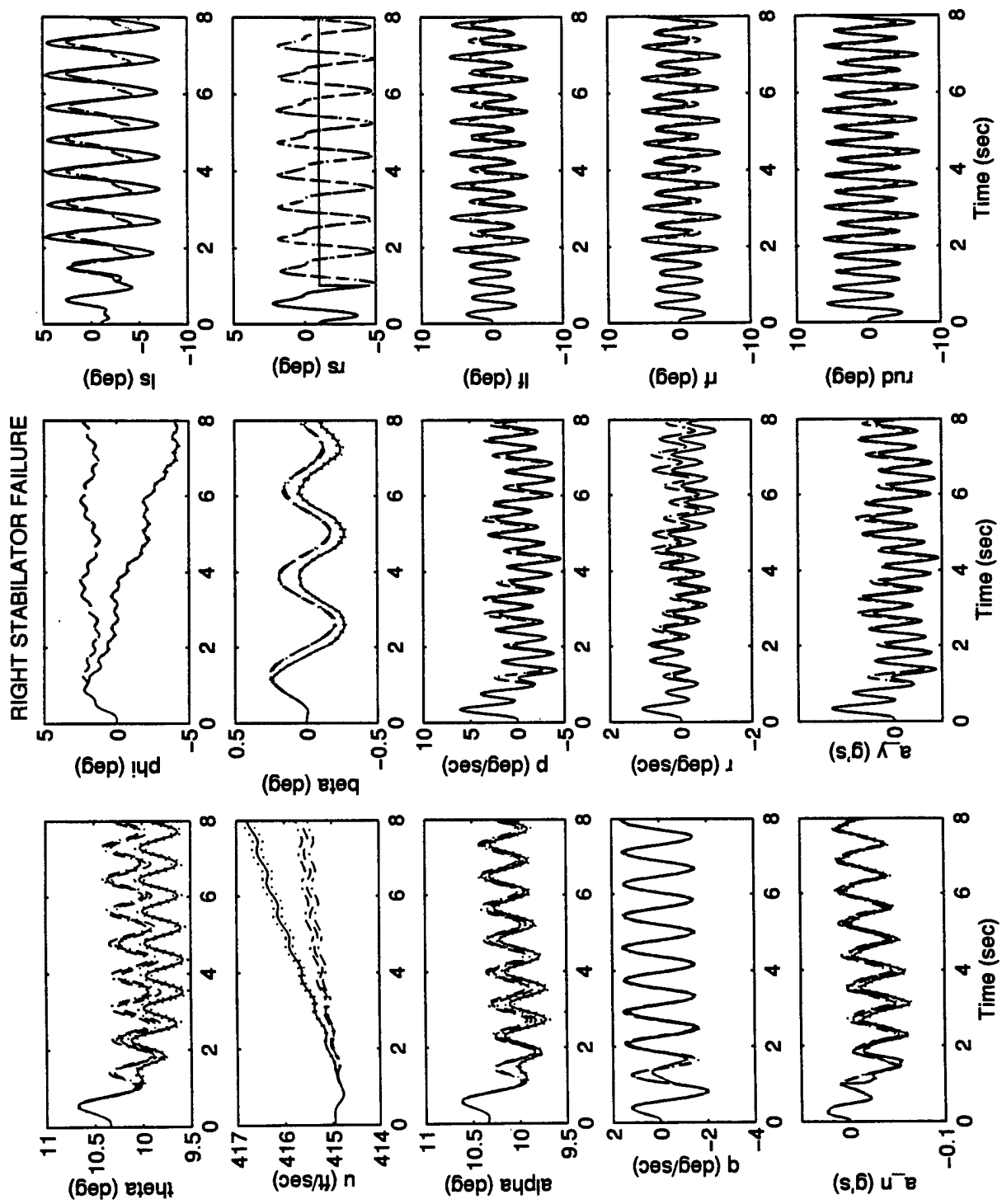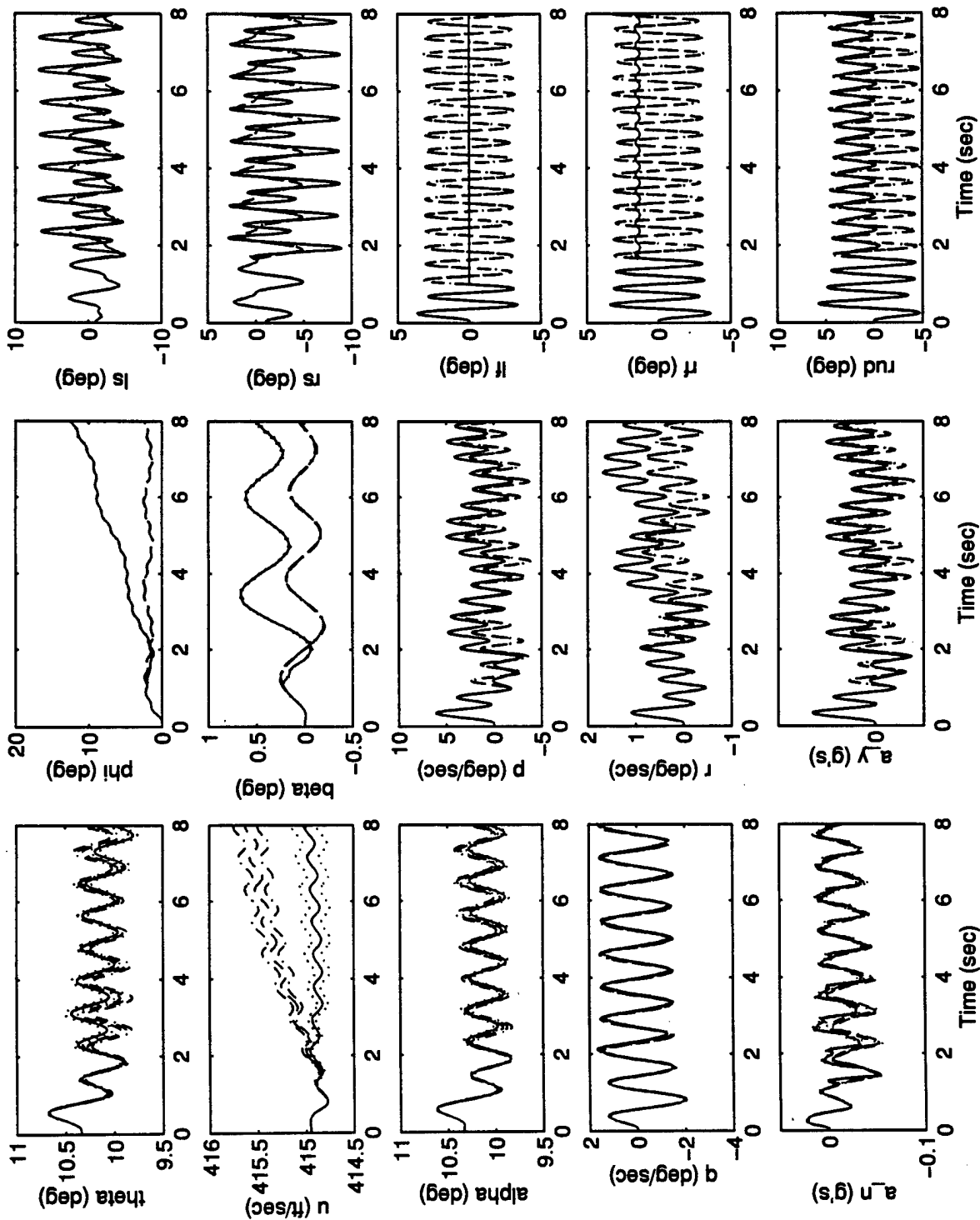
FULLY FUNCTIONAL AIRCRAFT

LEFT STABILATOR FAILURE

RIGHT STABILATOR FAILURE

LEFT FLAPERON FAILURE

RIGHT FLAPERON FAILURE

RUDDER FAILURE

Appendix F.1: State Plots for Single 75% Actuator Impairments (ε =.25), Control Redistribution

'OFF', Dither 'ON', No Maneuvers

This appendix contains the State Plots for cases of single, 75% actuator impairments without aircraft maneuvering or Control Reconfiguration (Redistribution), but with control dithering (Section 4.12.1 with Appendix B.1). Each page of State Plots in this appendix contains three columns of five plots and corresponds to one impairment condition, or test point. The first column shows the aircraft longitudinal states and normal acceleration (a_n). Column two shows lateral-directional states and lateral acceleration (a_y). The third column, of most interest to us, displays actuator positions (not commands). Two actual time histories, the result of a 10 Monte Carlo simulation run of each impairment condition, are plotted on each of the 15 subplots. The first time history, a "dashed / dashed-dotted" trace, represents the "mean ± one standard deviation" of the *fully functional* aircraft response. The second time history is a "solid line / dotted" trace and represents the response of the *impaired* aircraft at the given impairment condition.
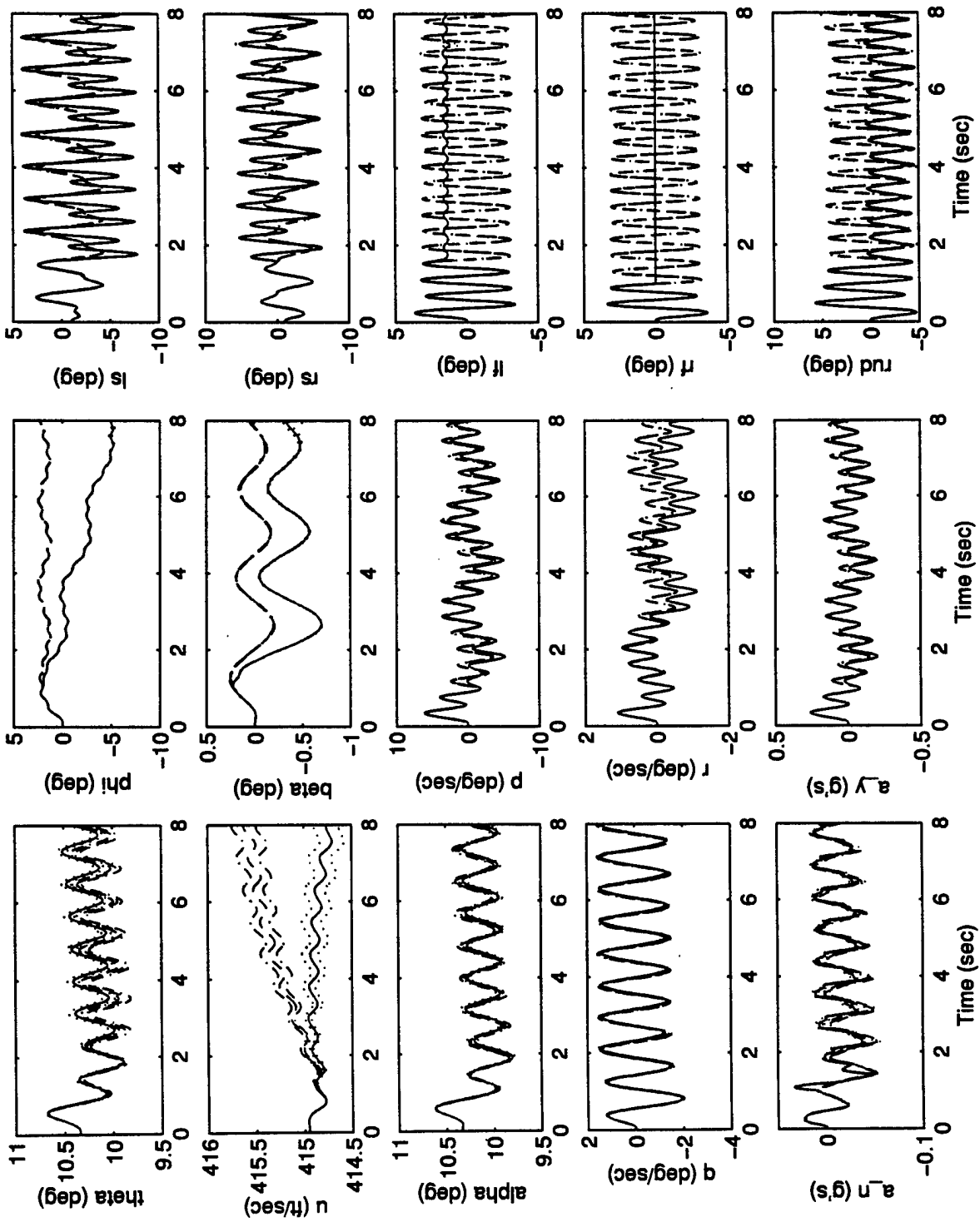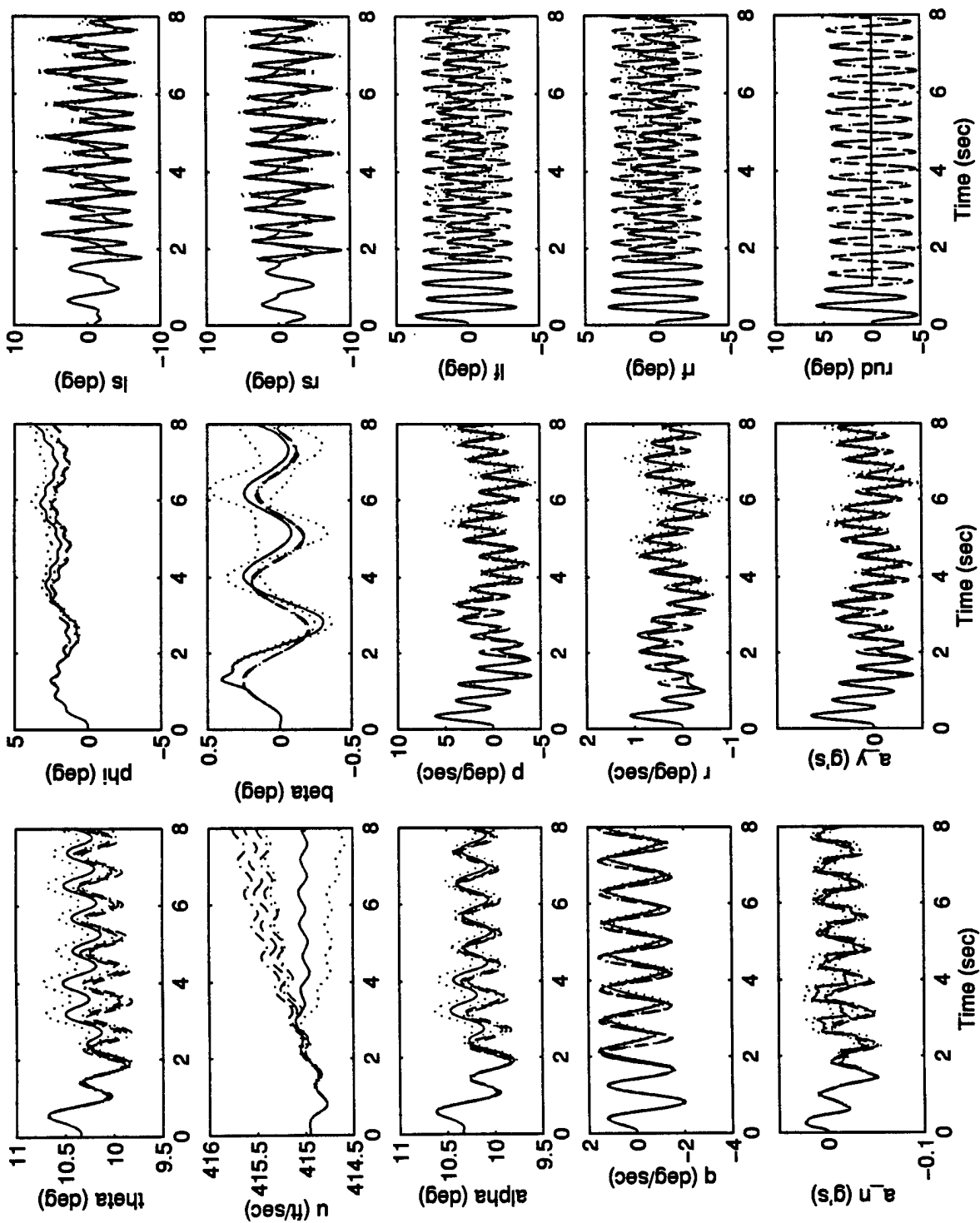
FULLY FUNCTIONAL AIRCRAFT

LEFT STABILATOR FAILURE

RIGHT STABILATOR FAILURE

LEFT FLAPERON FAILURE
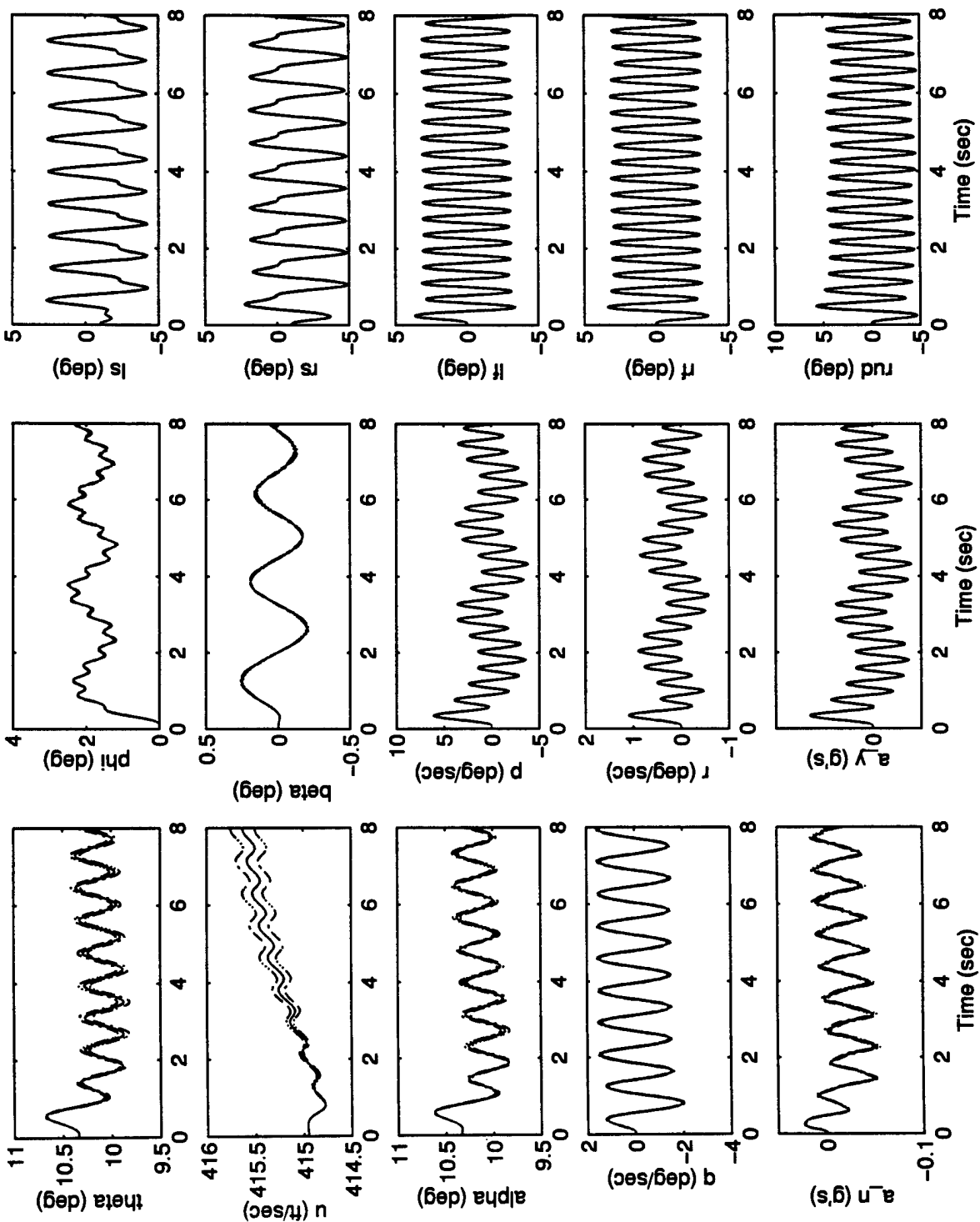
RIGHT FLAPERON FAILURE

RUDDER FAILURE

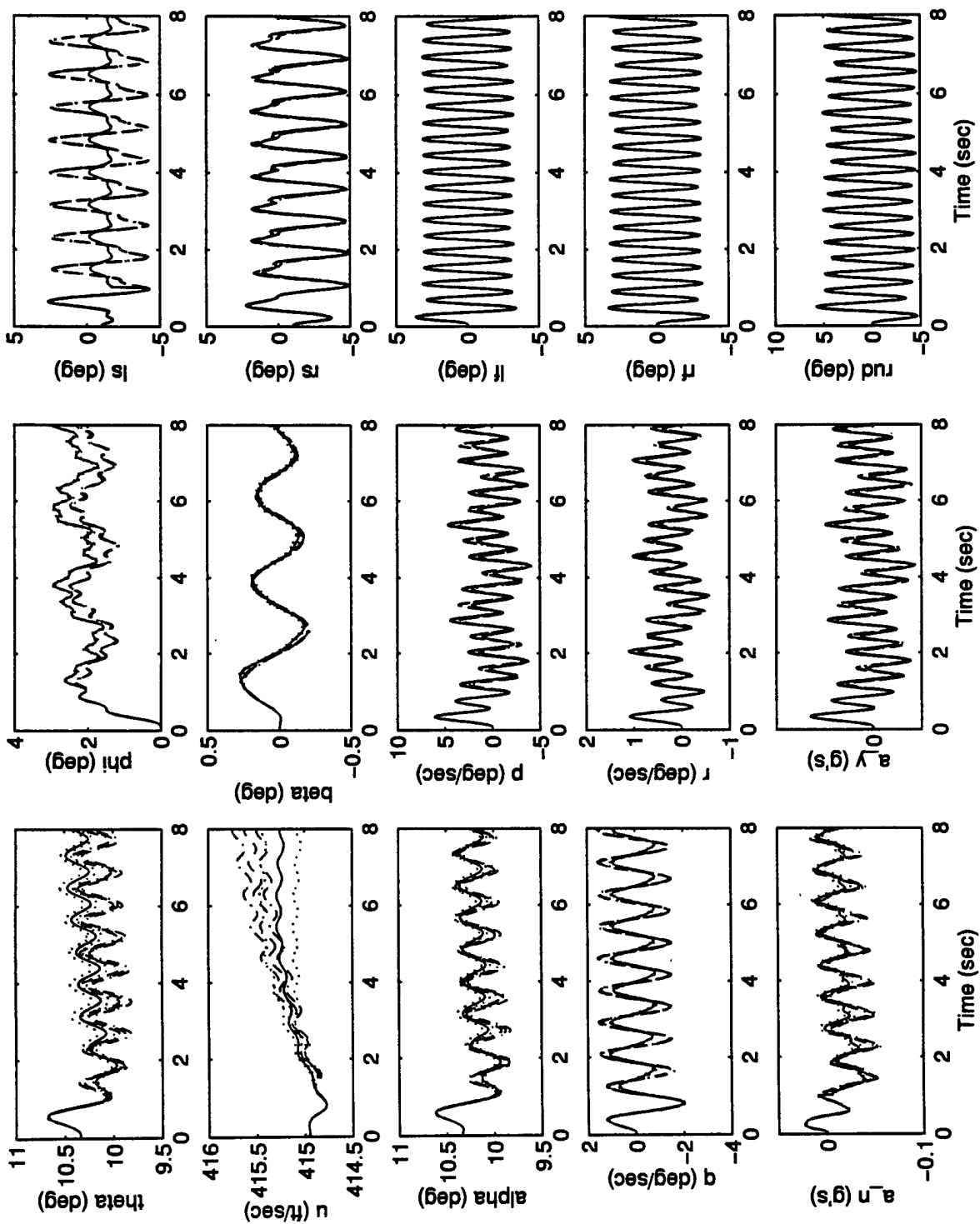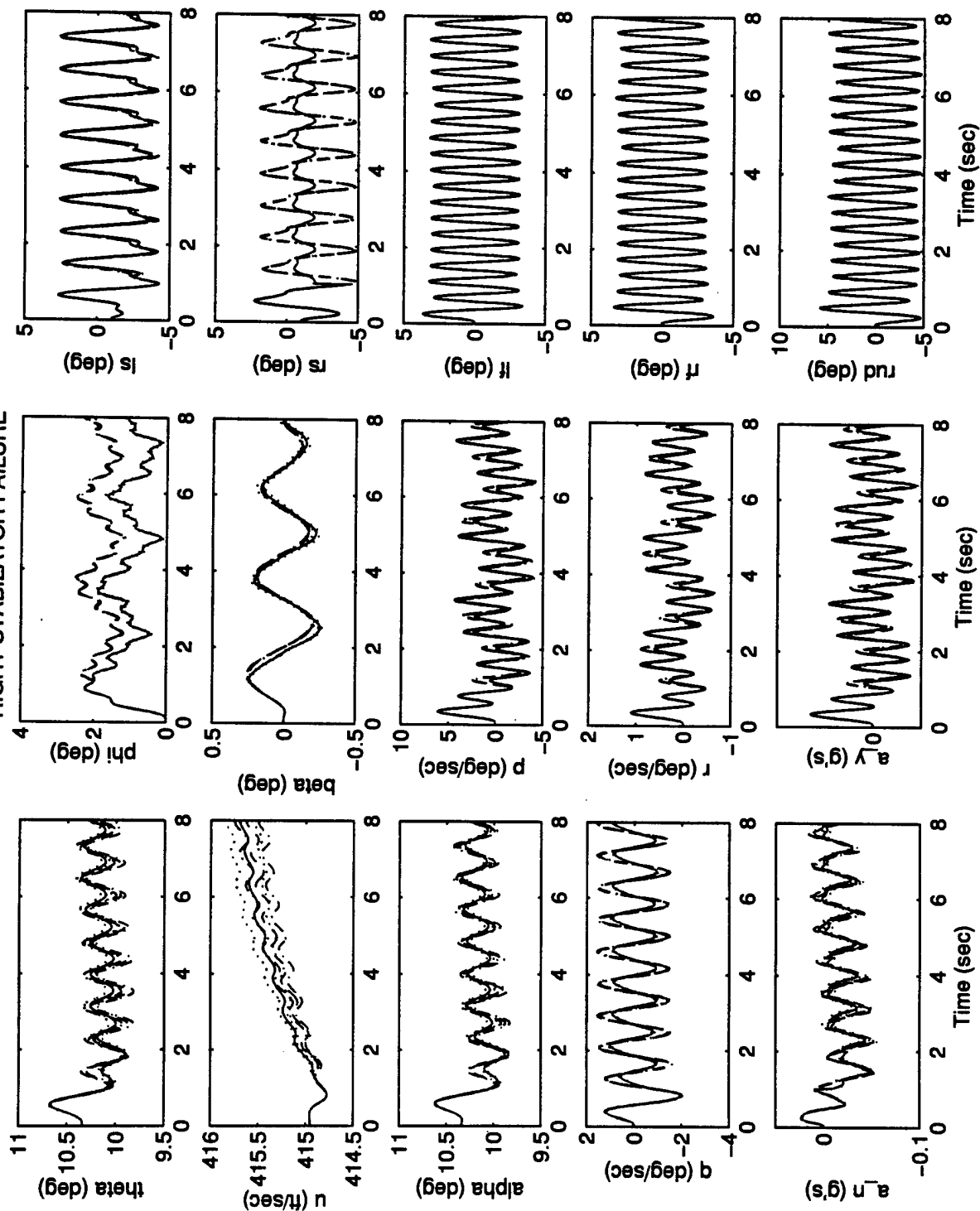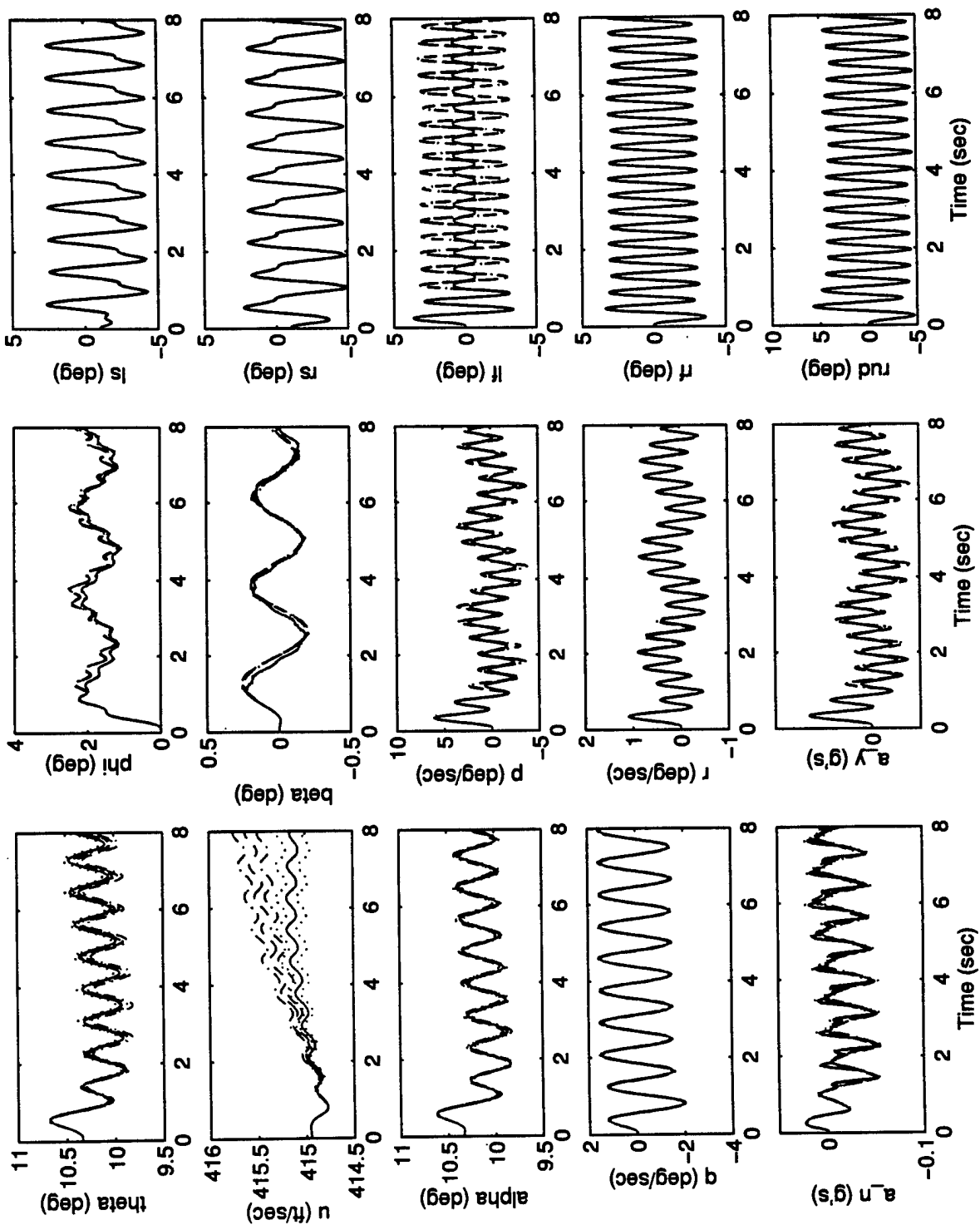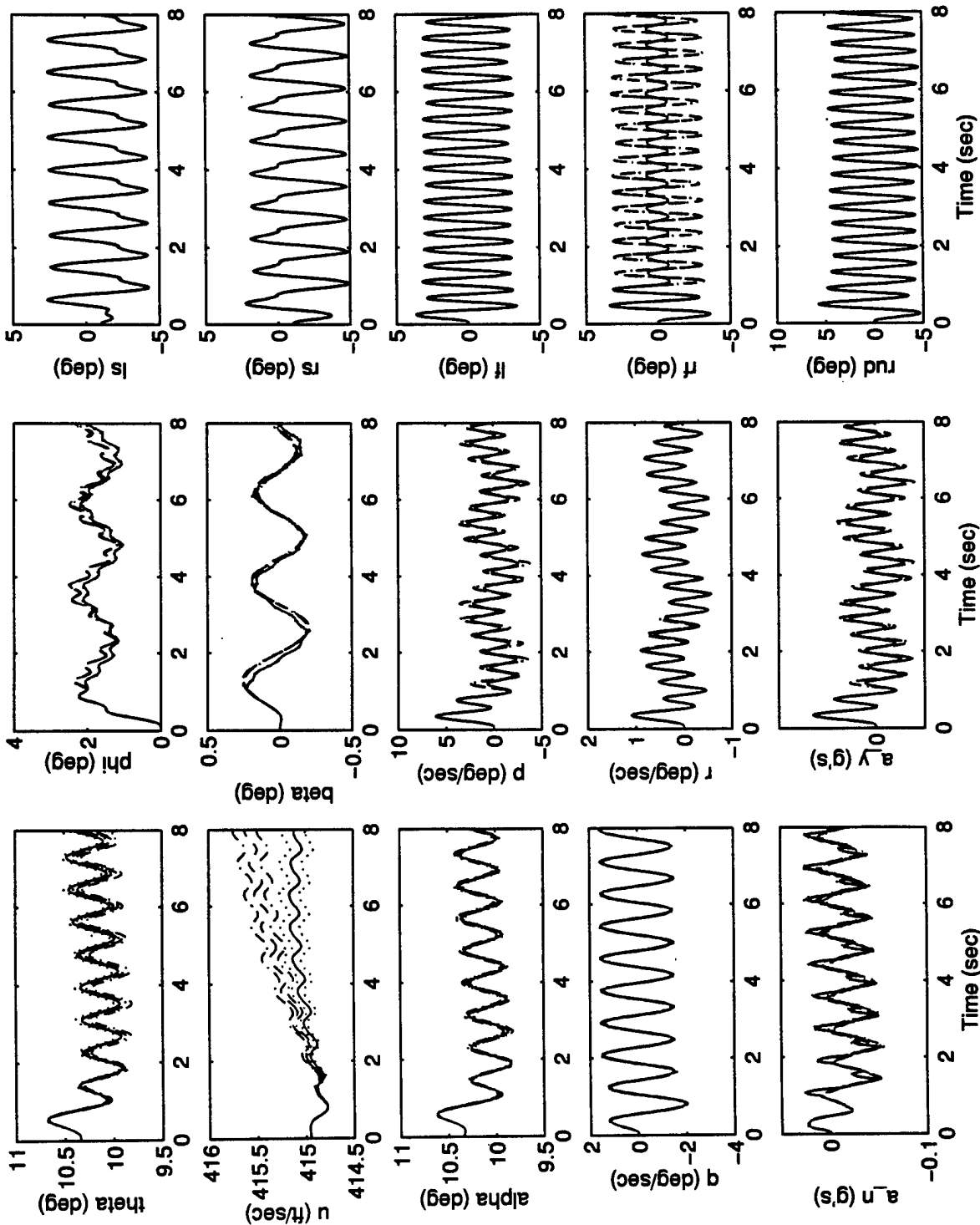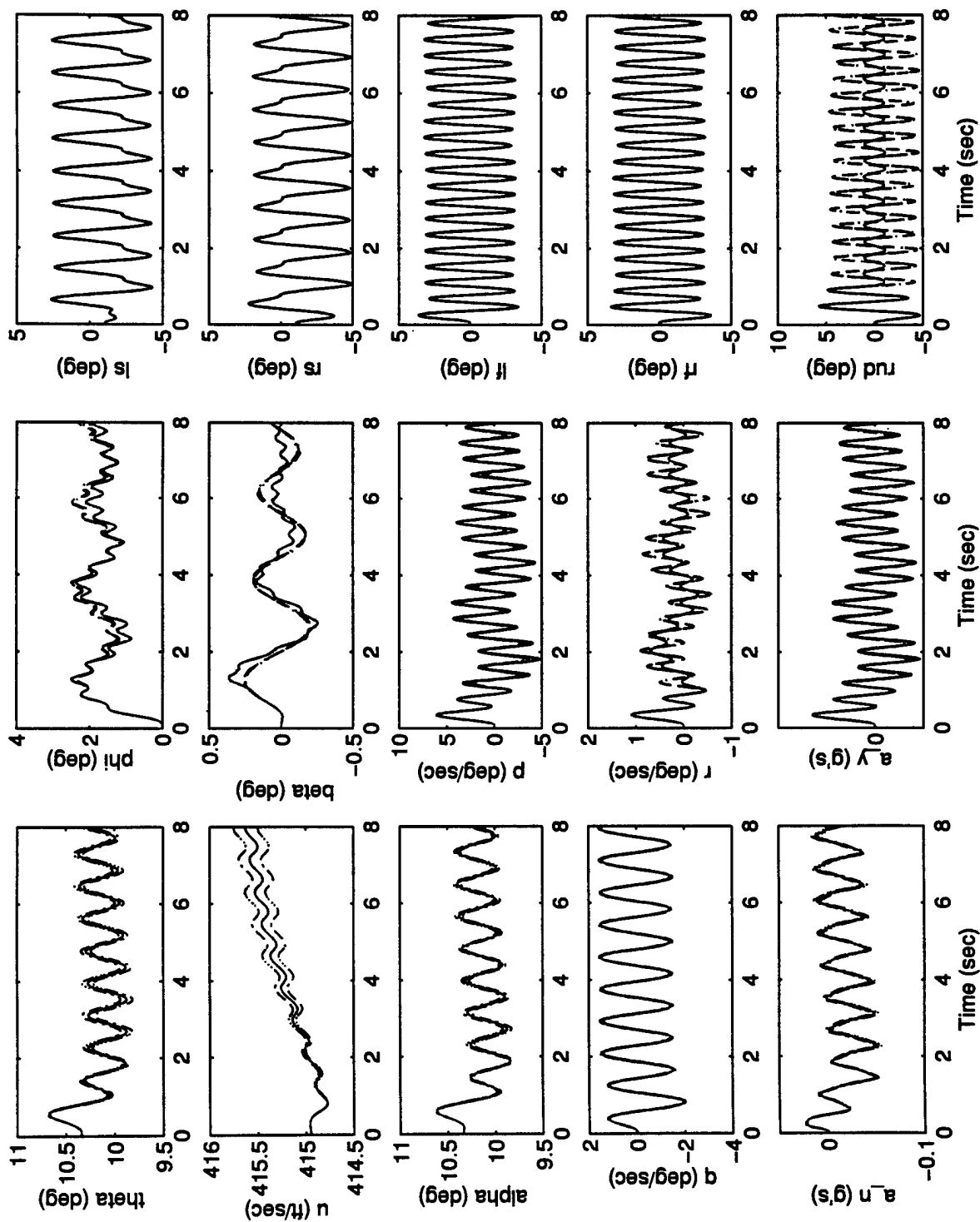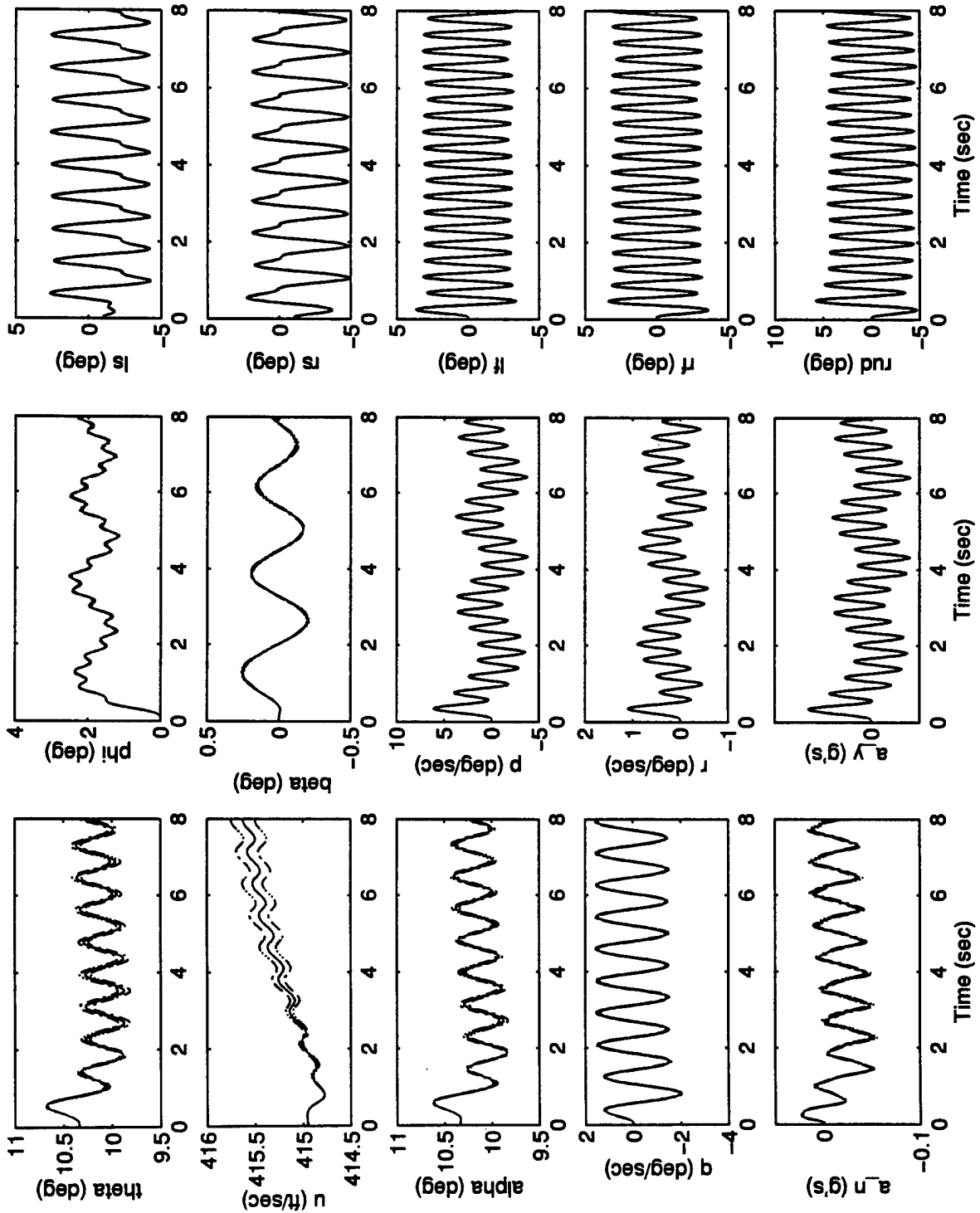*Appendix F.2: State Plots for Single 75% Actuator Impairments ($\varepsilon = .25$), Control Redistribution*

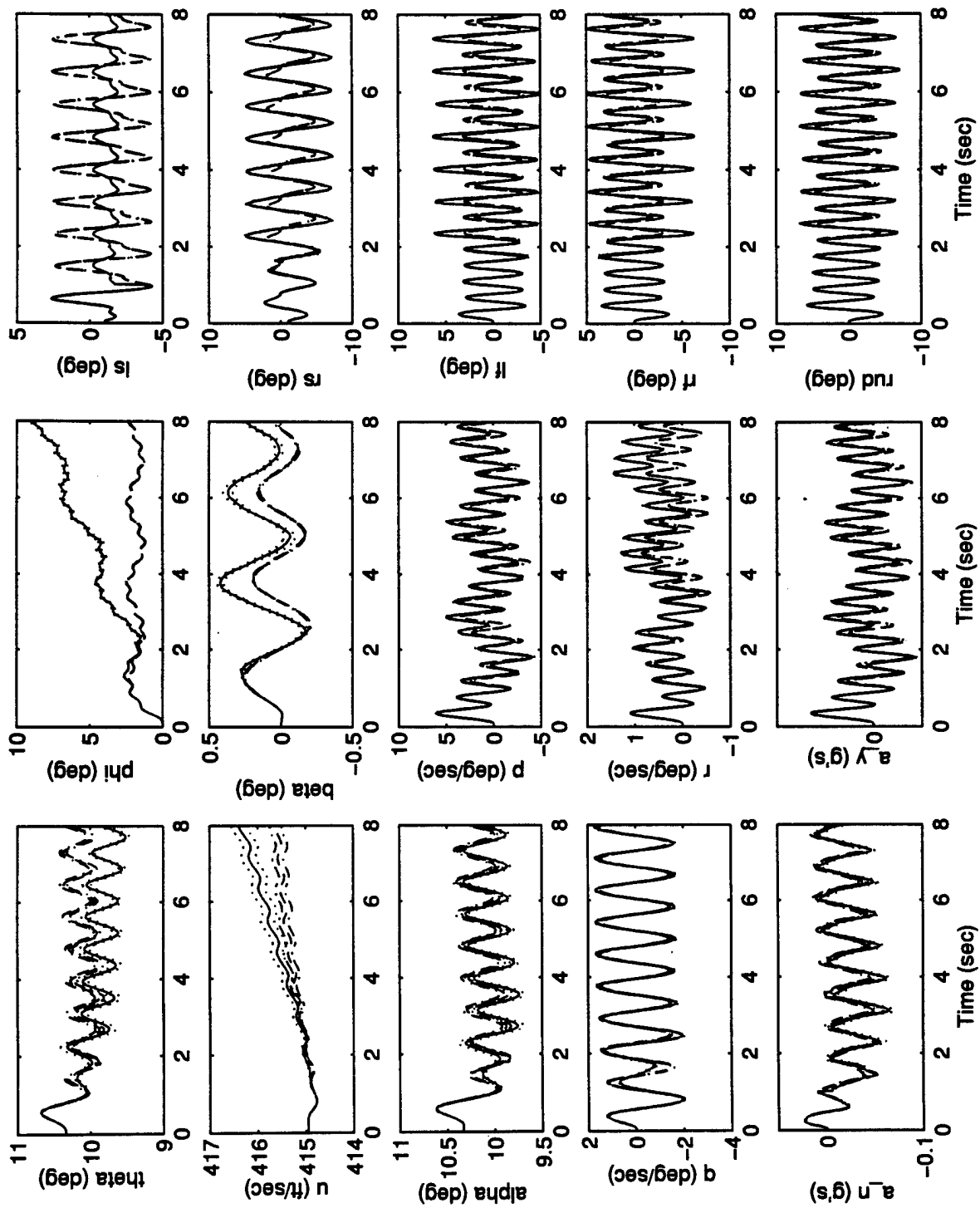*'ON', Dither 'ON', No Maneuvers*

This appendix contains the State Plots for cases of single, 75% actuator impairments without aircraft maneuvering, but with Control Reconfiguration (Redistribution) and with control dithering (Section 4.12.2 with Appendix B.2). Each page of State Plots in this appendix contains three columns of five plots and corresponds to one impairment condition, or test point. The first column shows the aircraft longitudinal states and normal acceleration (a_n). Column two shows lateral-directional states and lateral acceleration (a_y). The third column, of most interest to us, displays actuator positions (not commands). Two actual time histories, the result of a 10 Monte Carlo simulation run of each impairment condition, are plotted on each of the 15 subplots. The first time history, a "dashed / dashed-dotted" trace, represents the "mean ± one standard deviation" of the *fully functional* aircraft response. The second time history is a "solid line / dotted" trace and represents the response of the *impaired* aircraft at the given impairment condition.

The reader should note, when viewing the plots of surface positions for all impairment cases, that these results are not as expected. One would wish to see surface positions approaching those of the unimpaired aircraft, since, with an ideal identification of the impaired actuator, Control Redistribution should boost that actuator's command to compensate for the impairment. What is *actually* observed, however, is that the surface positions are virtually identical to those seen in Appendix E.2 for Control Reconfiguration under cases of total actuator impairments. This demonstrates that the MMAE algorithm is erroneously declaring total impairments in these cases, and that Control Reconfiguration is occurring based on total (not the actual 75%) impairment.
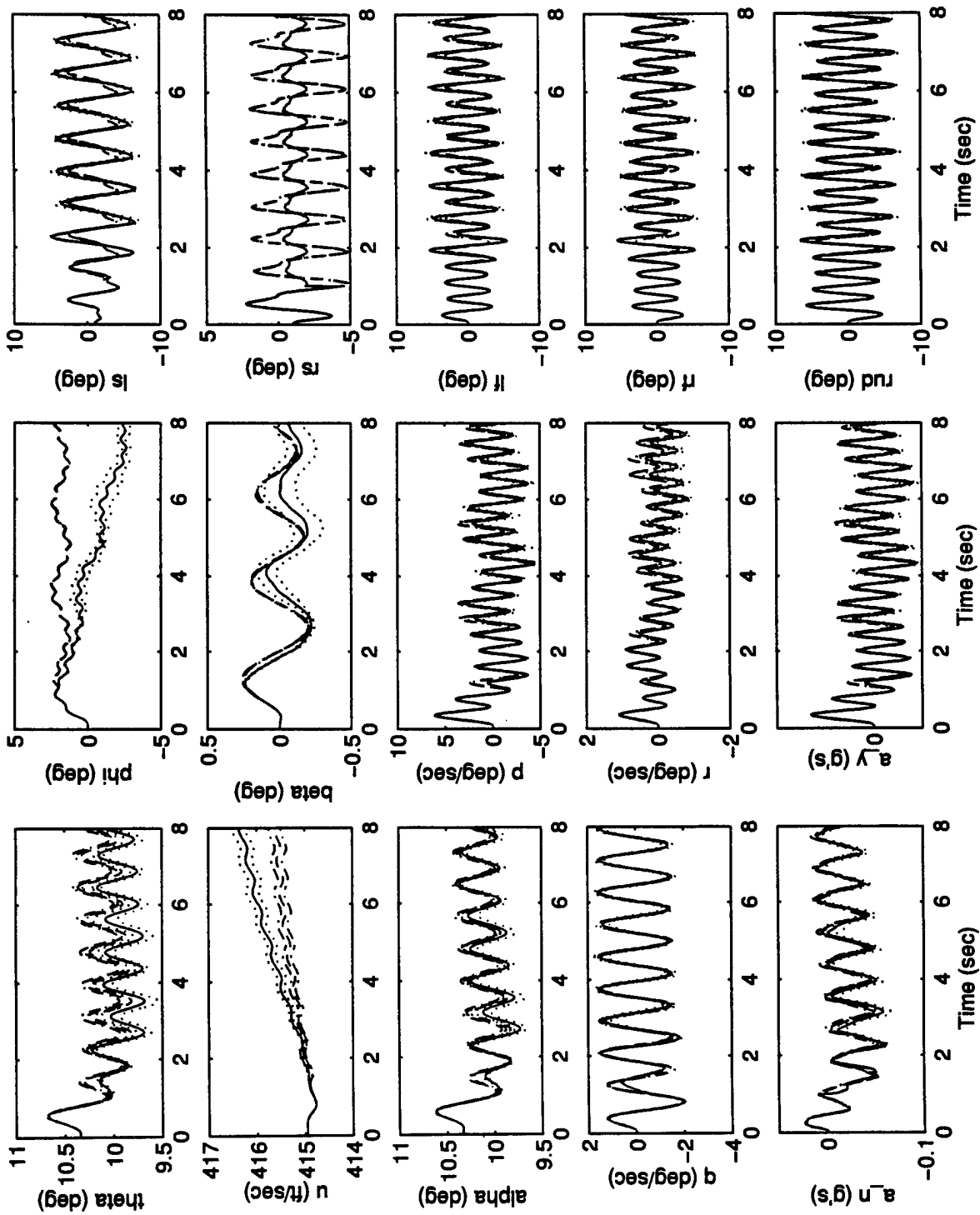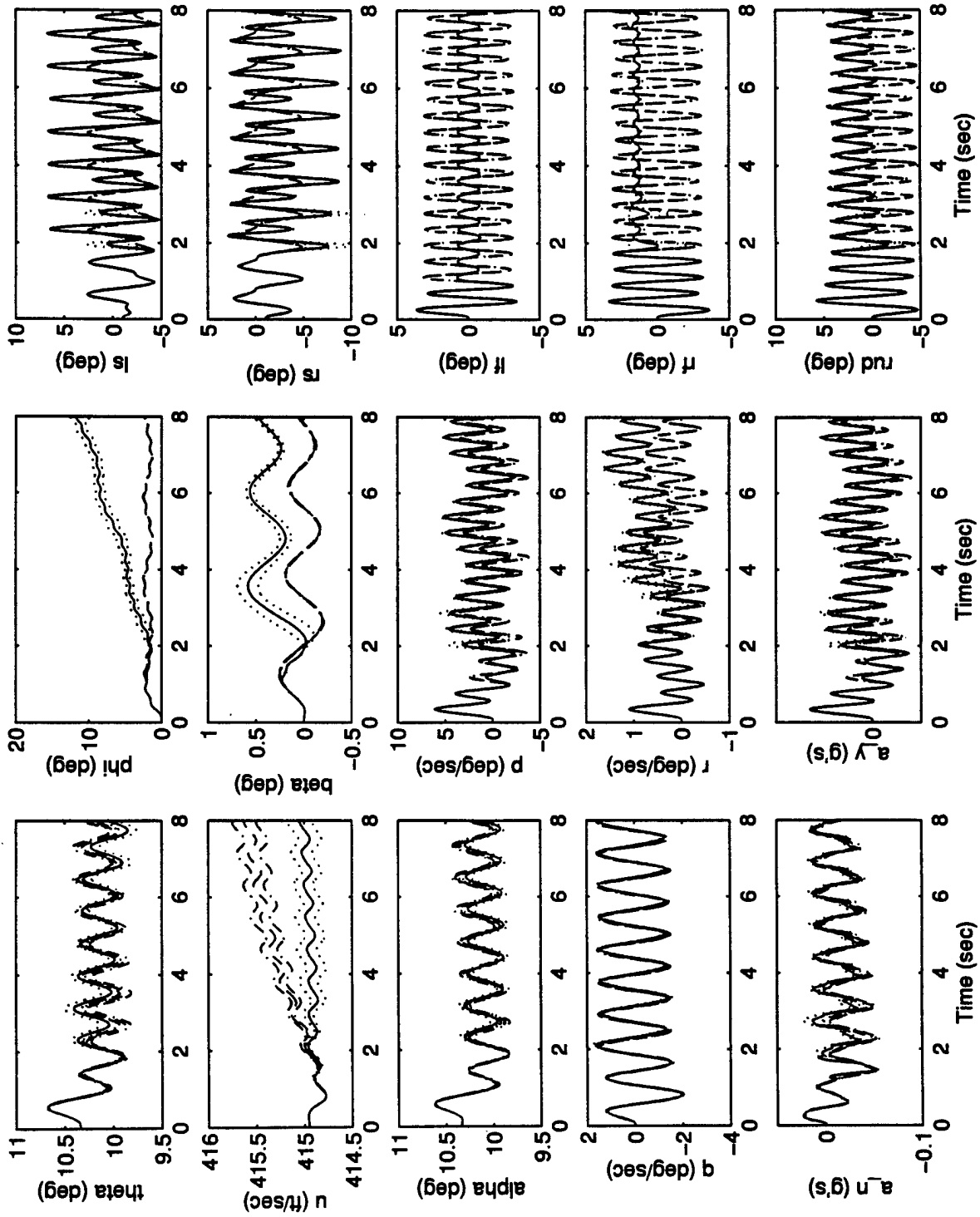
FULLY FUNCTIONAL AIRCRAFT

theta (deg)
u (ft/sec)
alpha (deg)
q (deg/sec)
a_n (g's)

phi (deg)
beta (deg)
p (deg/sec)
r (deg/sec)
a_y (g's)

ls (deg)
rs (deg)
lf (deg)
rf (deg)
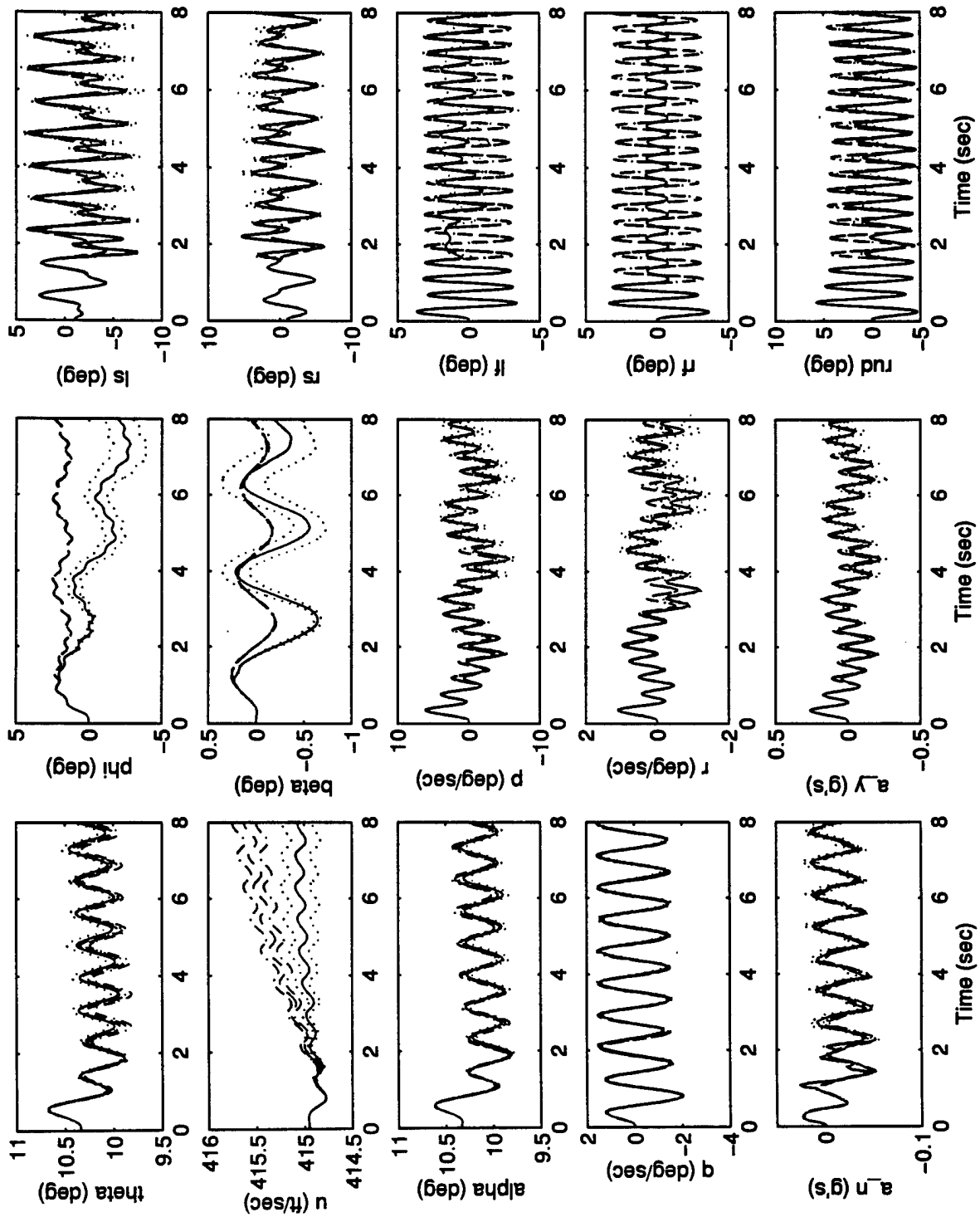rud (deg)

Time (sec)
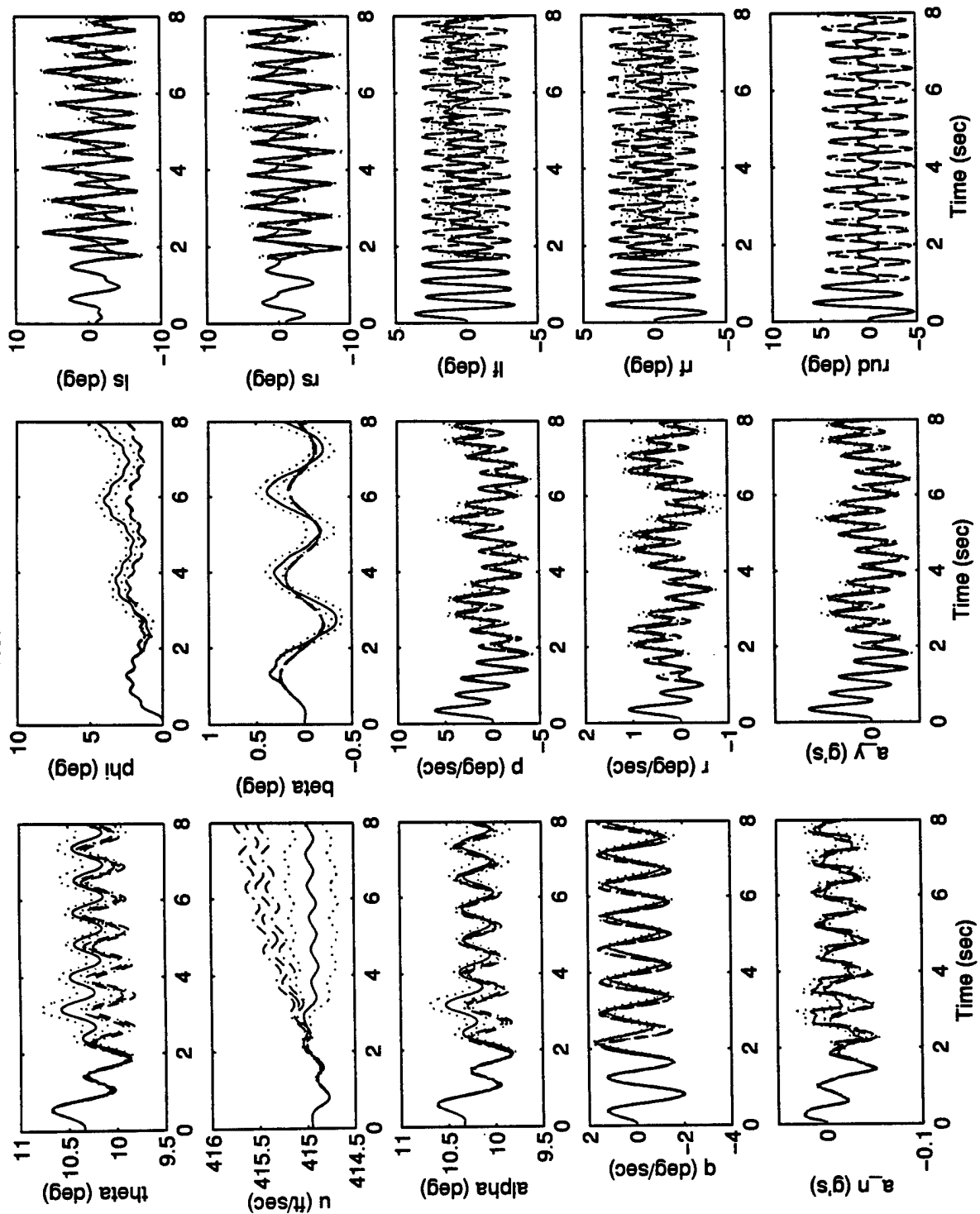
LEFT STABILATOR FAILURE

RIGHT STABILATOR FAILURE
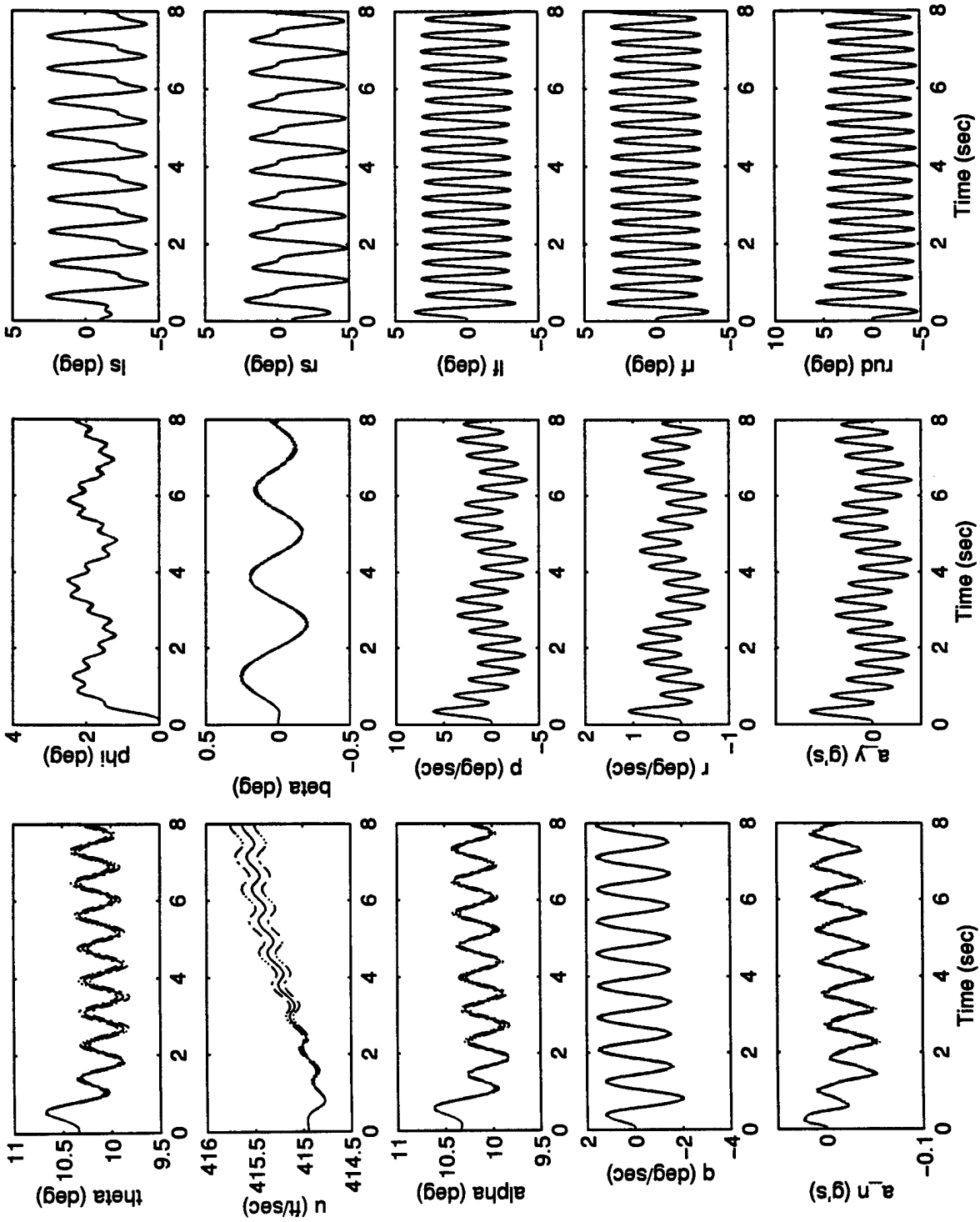
LEFT FLAPERON FAILURE

RIGHT FLAPERON FAILURE

RUDDER FAILURE

Appendix G.1: State Plots for Single 50% Actuator Impairments (ε =.5), Control Redistribution
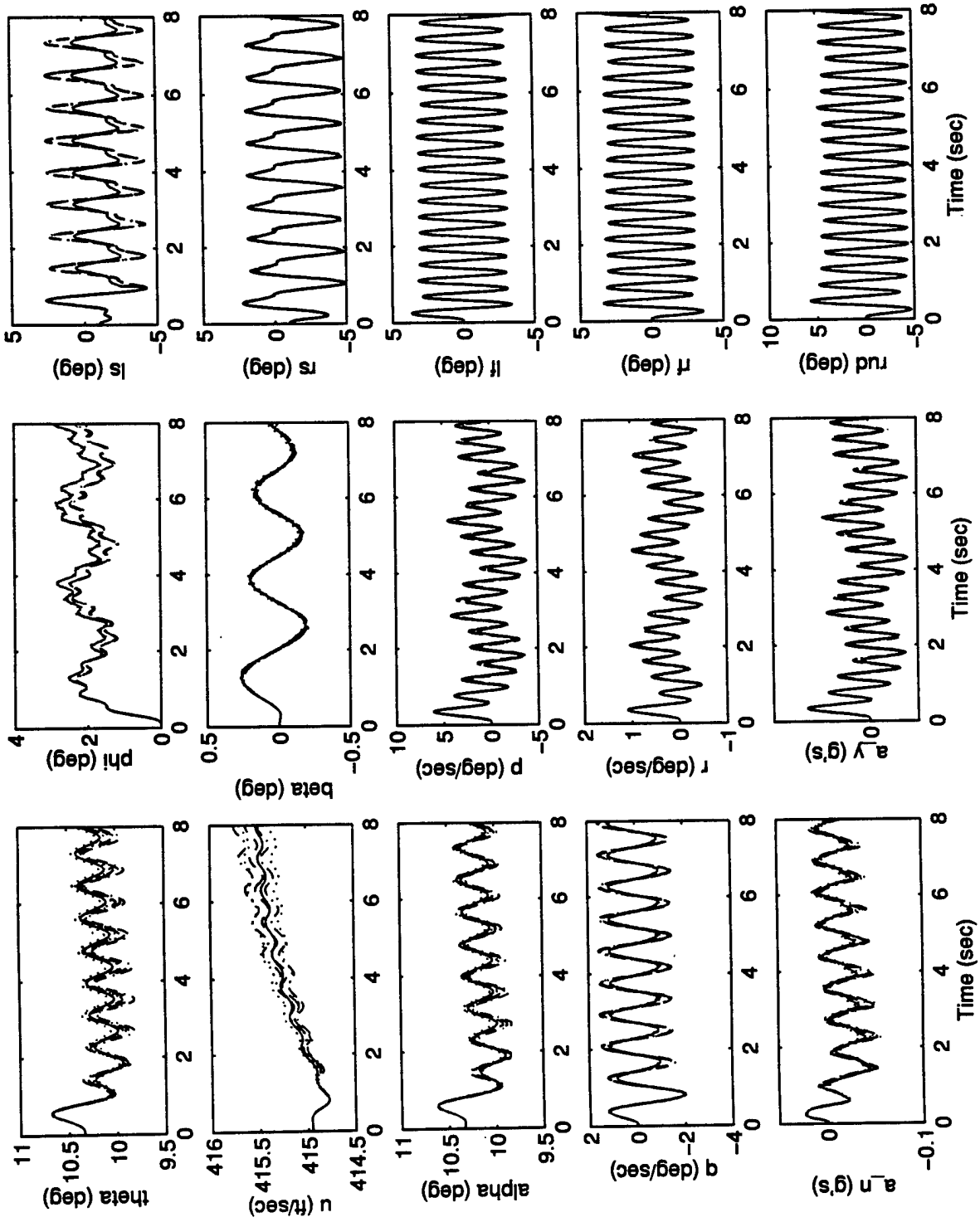
'OFF', Dither 'ON', No Maneuvers

This appendix contains the State Plots for cases of single, 50% actuator impairments without aircraft maneuvering or Control Reconfiguration (Redistribution), but with control dithering (Section 4.13.1 with Appendix C.1). Each page of State Plots in this appendix contains three columns of five plots and corresponds to one impairment condition, or test point. The first column shows the aircraft longitudinal states and normal acceleration (a_n). Column two shows lateral-directional states and lateral acceleration (a_y). The third column, of most interest to us, displays actuator positions (not commands). Two actual time histories, the result of a 10 Monte Carlo simulation run of each impairment condition, are plotted on each of the 15 subplots. The first time history, a "dashed / dashed-dotted" trace, represents the "mean ± one standard deviation" of the *fully functional* aircraft response. The second time history is a "solid line / dotted" trace and represents the response of the *impaired* aircraft at the given impairment condition.
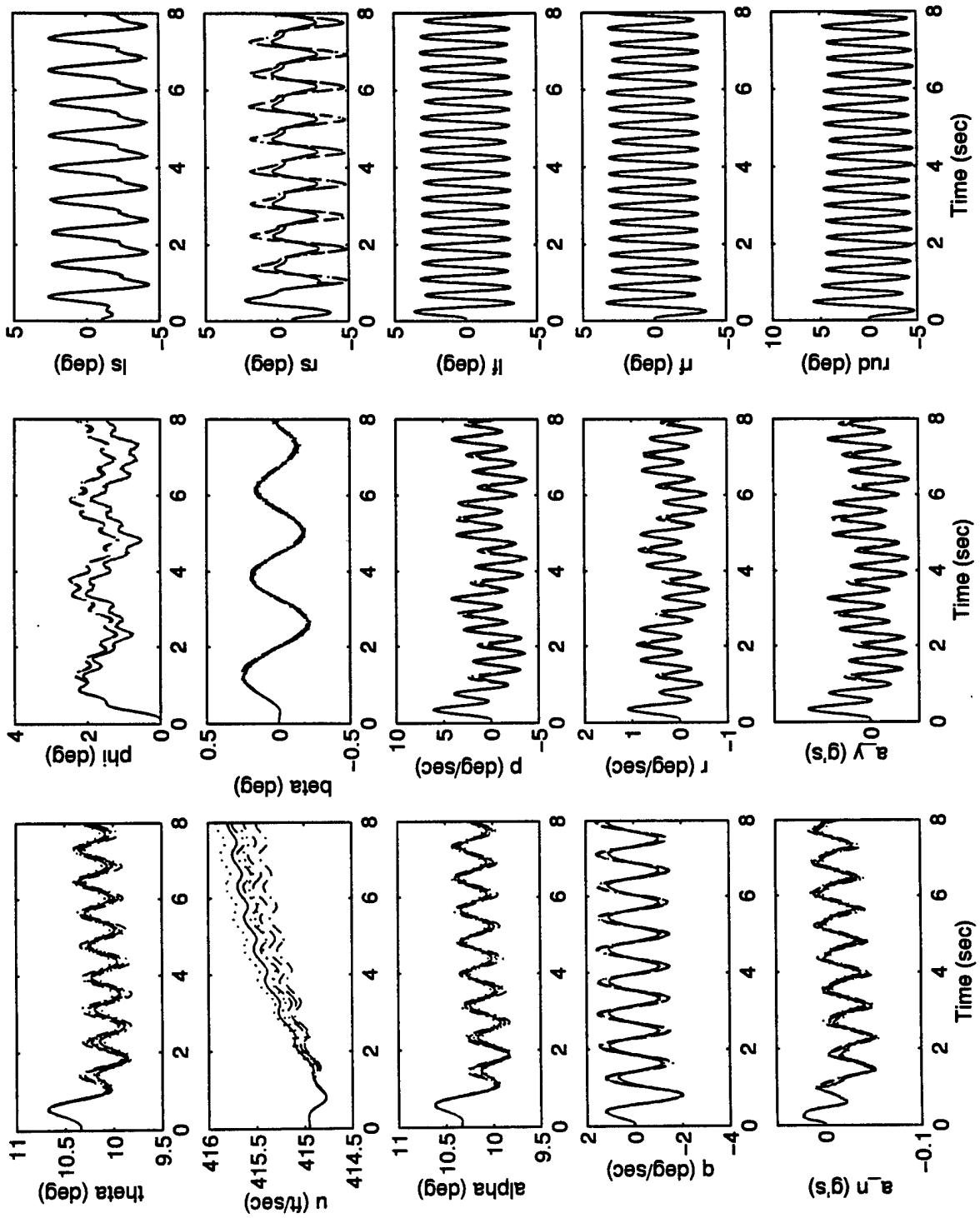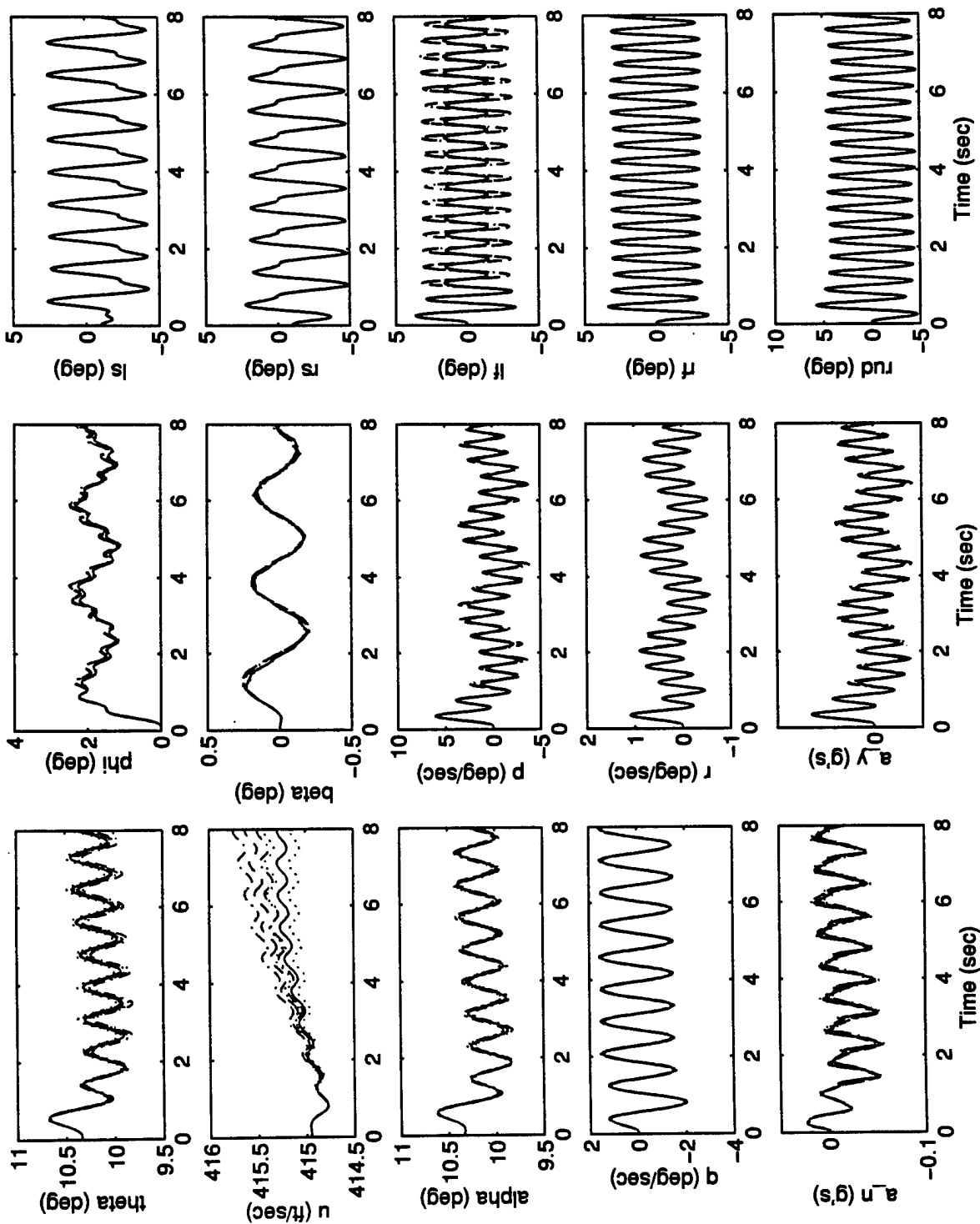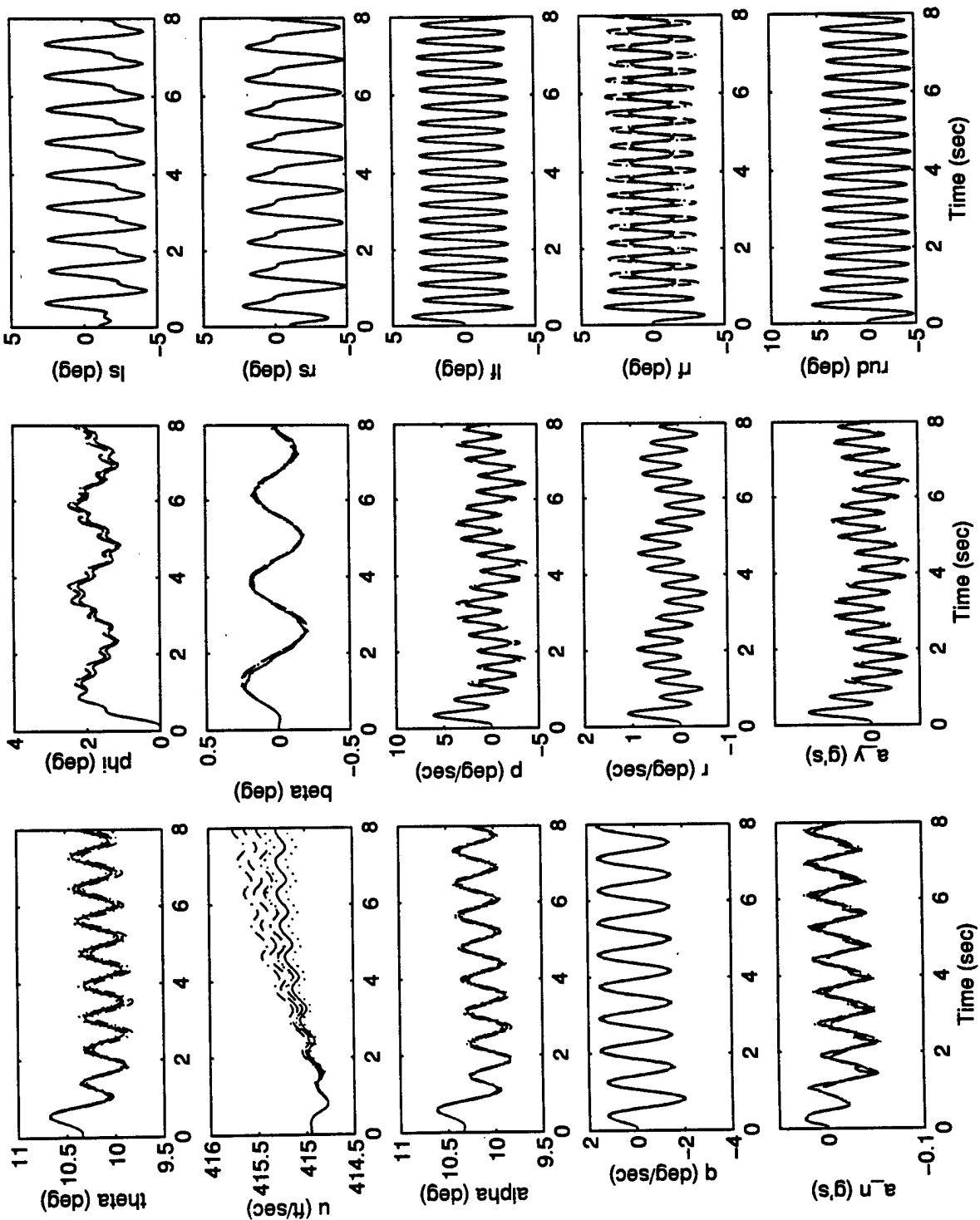
FULLY FUNCTIONAL AIRCRAFT

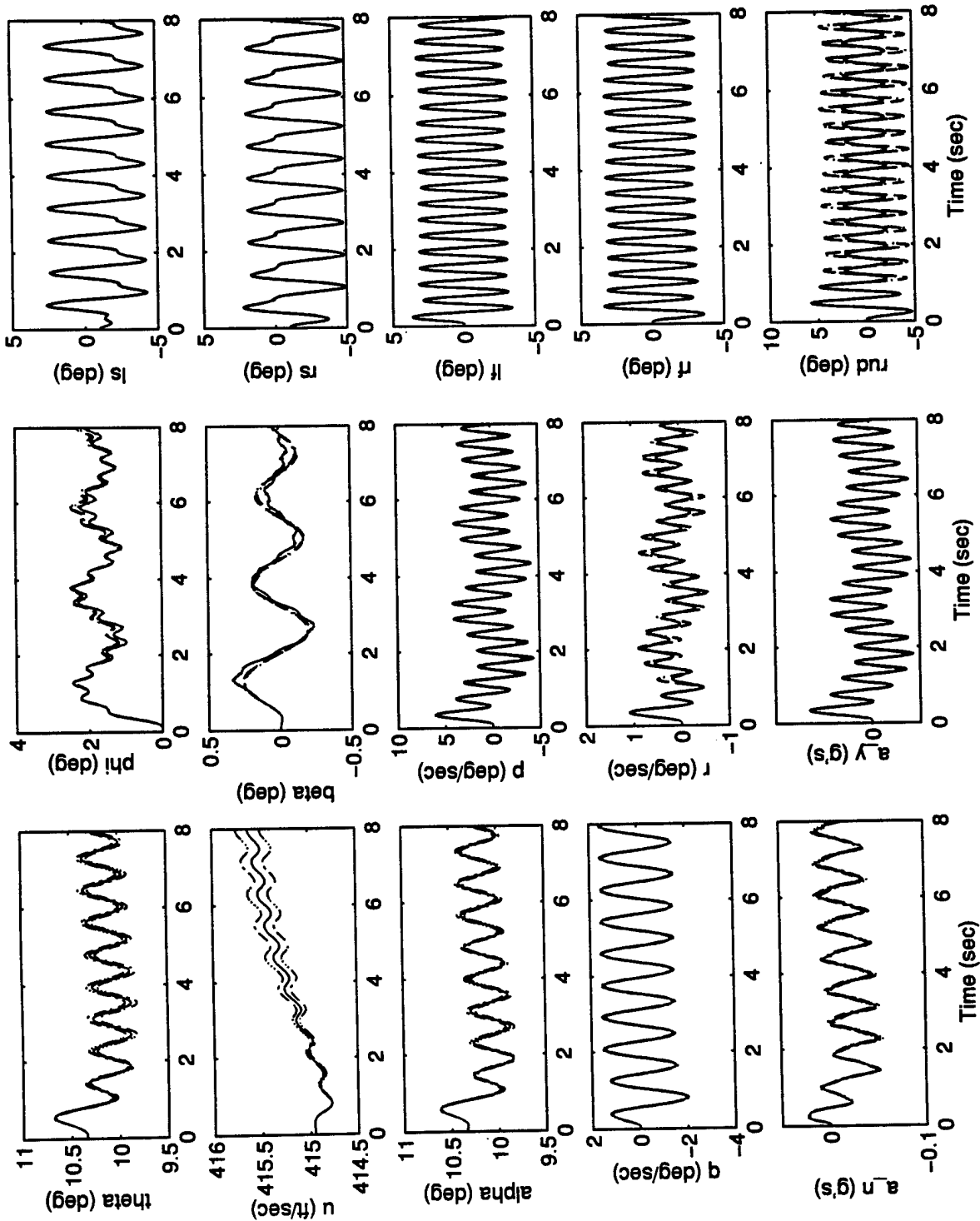LEFT STABILATOR FAILURE

RIGHT STABILATOR FAILURE

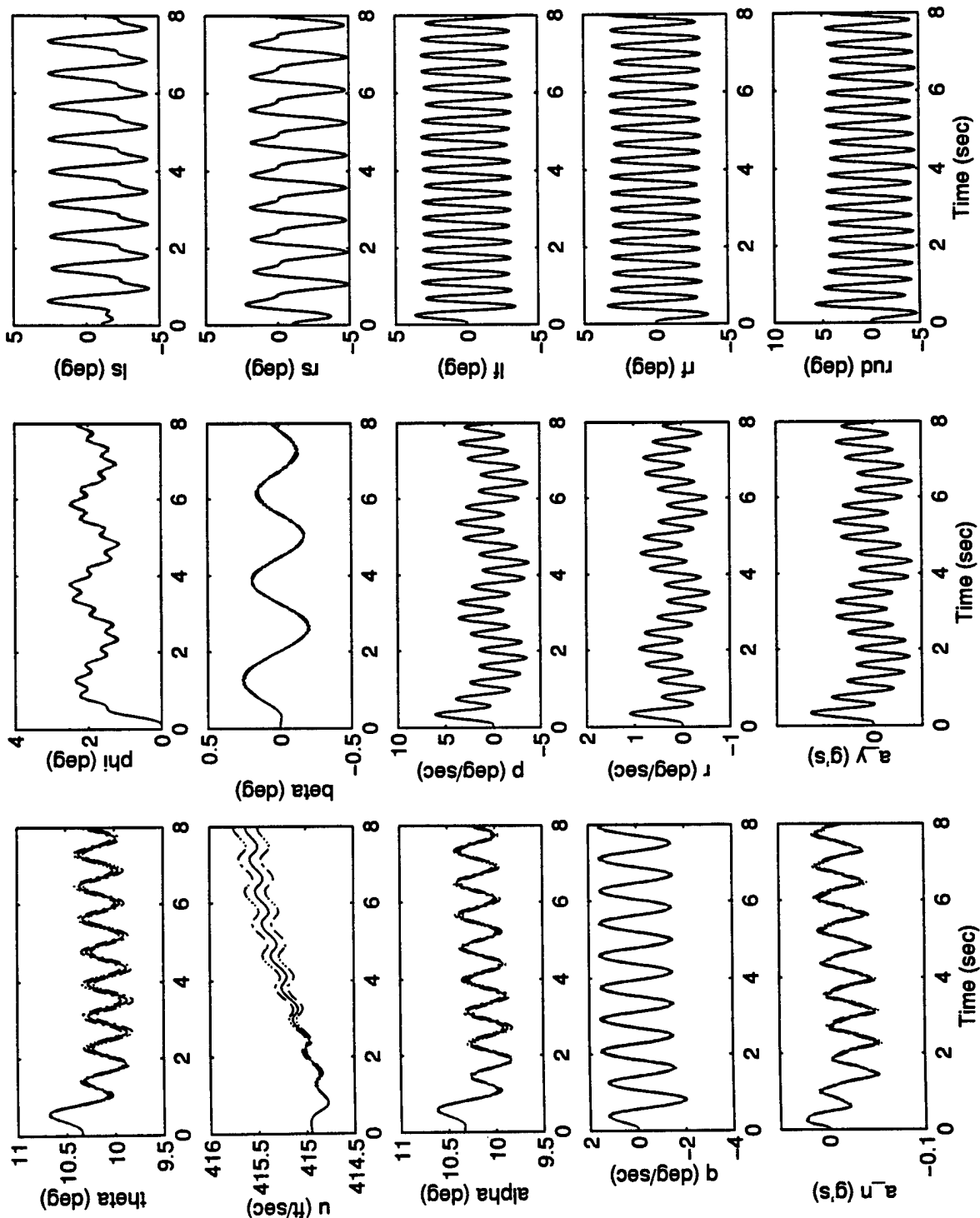LEFT FLAPERON FAILURE

RIGHT FLAPERON FAILURE

RUDDER FAILURE

Appendix G.2: State Plots for Single 50% Actuator Impairments (ε = .5), Control Redistribution 'ON', Dither 'ON', No Maneuvers
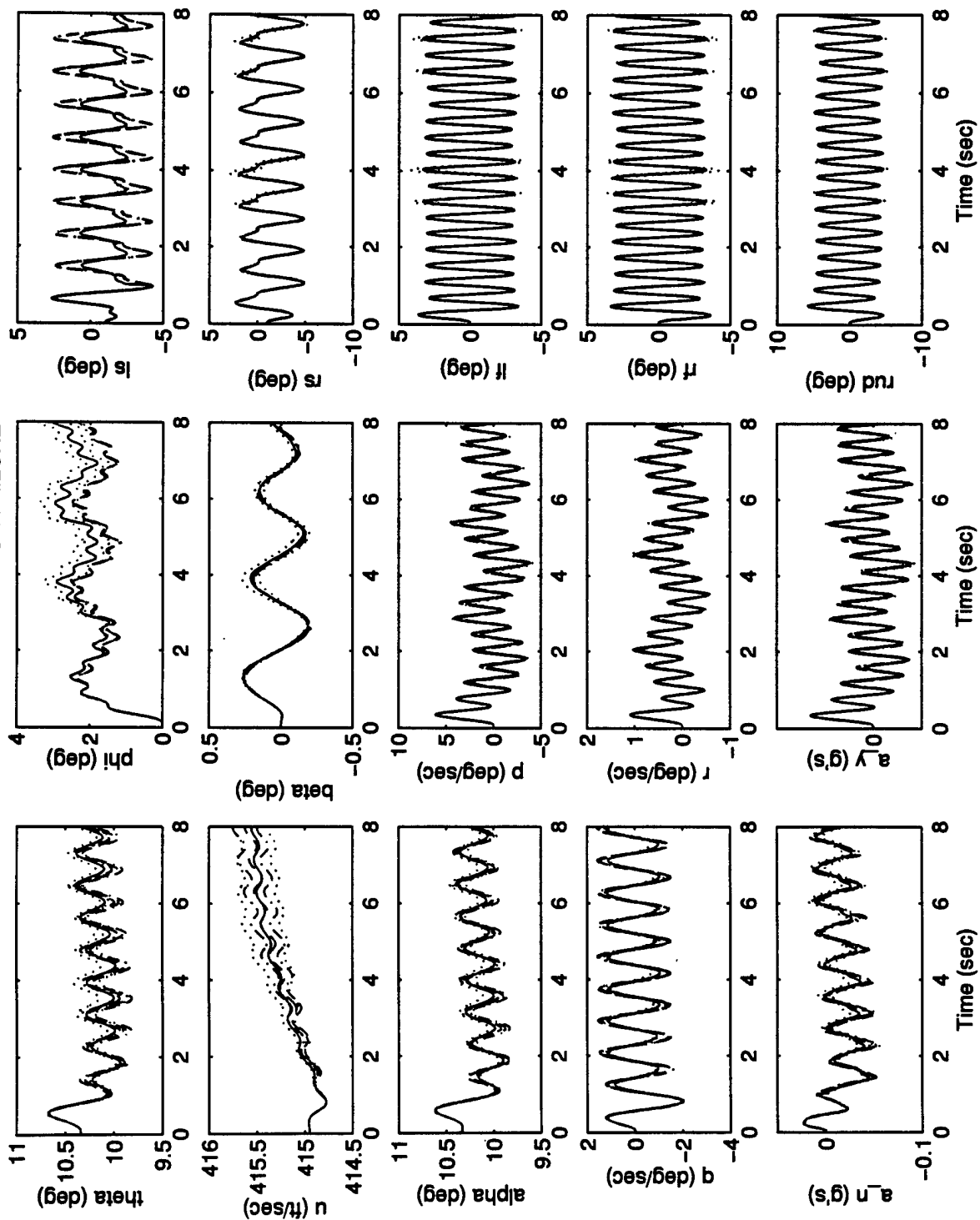
This appendix contains the State Plots for cases of single, 50% actuator impairments without aircraft maneuvering. But with Control Reconfiguration (Redistribution) and with control dithering (Section 4.13.2 with Appendix C.2). Each page of State Plots in this appendix contains three columns of five plots and corresponds to one impairment condition, or test point. The first column shows the aircraft longitudinal states and normal acceleration (a_n). Column two shows lateral-directional states and lateral acceleration (a_y). The third column, of most interest to us, displays actuator positions (not commands). Two actual time histories, the result of a 10 Monte Carlo simulation run of each impairment condition, are plotted on each of the 15 subplots. The first time history, a "dashed / dashed-dotted" trace, represents the "mean ± one standard deviation" of the *fully functional* aircraft response. The second time history is a "solid line / dotted" trace and represents the response of the *impaired* aircraft at the given impairment condition.

The reader will notice that in all cases except for the case of a 50% rudder actuator impairment, the surface positions match those found in Appendix G.1 for the same impairment cases *without* Control Reconfiguration. This is to be expected, since the results of Section 4.5.1 and Table 4-3 show that, in all cases (except for the rudder), probability values are so small as to be non-detectable. Hence, the results for impairment cases *other than the rudder* in this appendix are due to the 50% actuator impairments being ignored by the current MMAE algorithm. The rudder, on the other hand, *is* being detected by MMAE and Control Reconfiguration is occurring. It is not however, what we wish to see, which is all actuator positions coming very close to their *unimpaired* values (for the same reasons given in Appendix F.2). We see that the rudder position is not being "boosted", as desired, to compensate for the rudder impairment. Instead, something close to Control Reconfiguration for a totally impaired rudder is occurring (see Appendix E.2), except for the flaperons, which, due to the "toothy" appearance of the surface position plots, look as if they might be under rate or position saturation conditions. A shortage of time prevented an in-depth analysis of the reasons for the results displayed in this appendix, but it is apparent that the root cause is a misidentification of the impairment by the current MMAE algorithm.
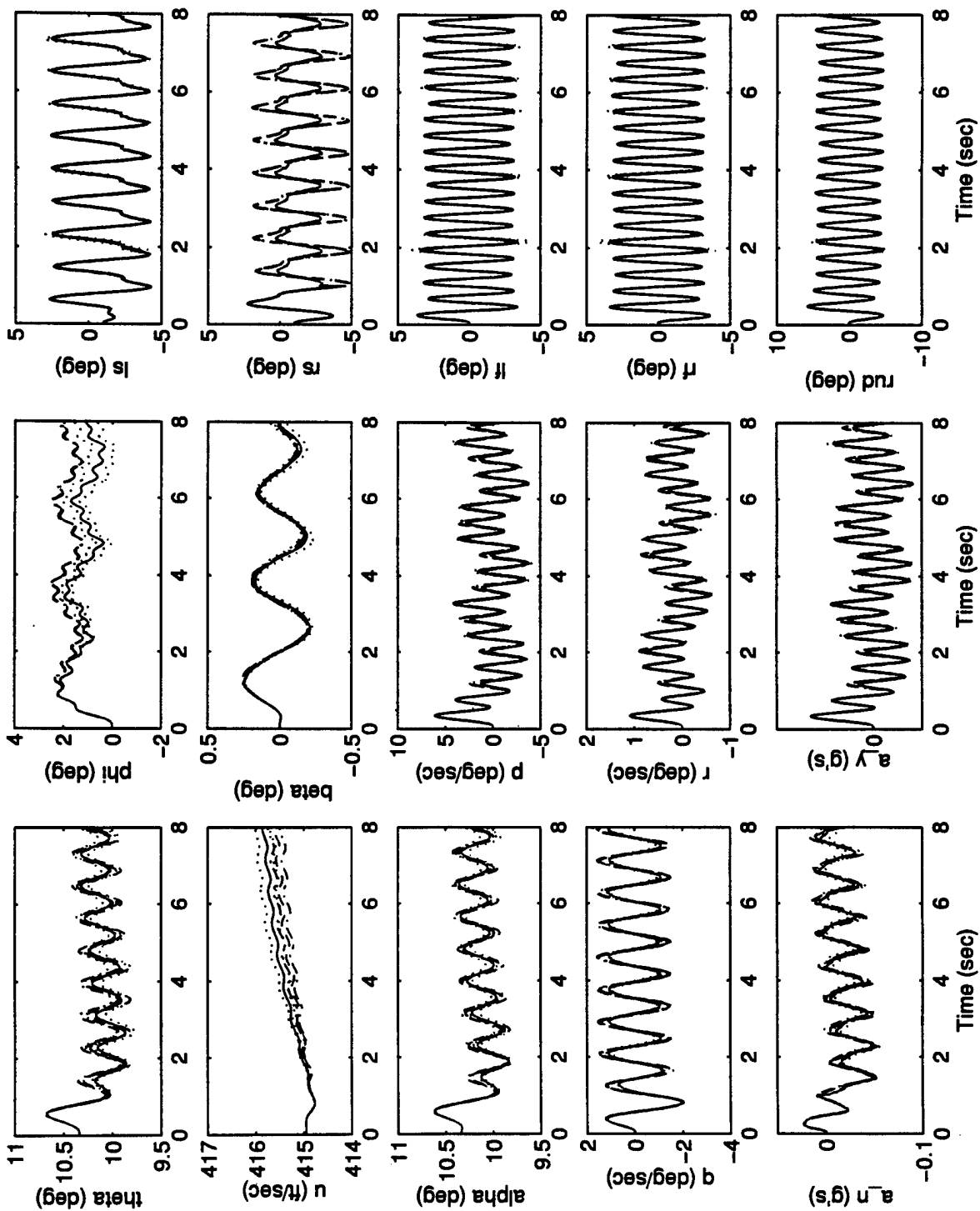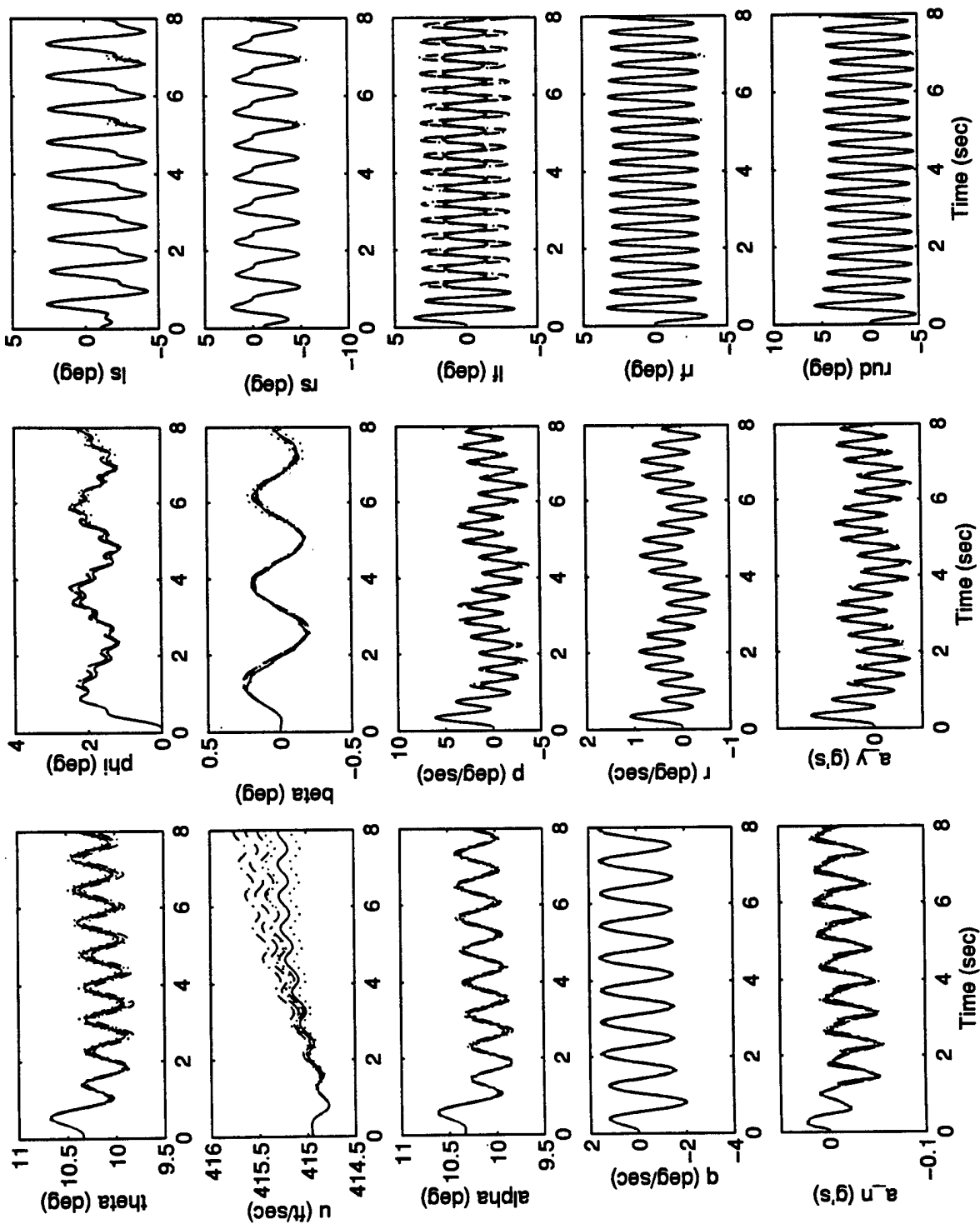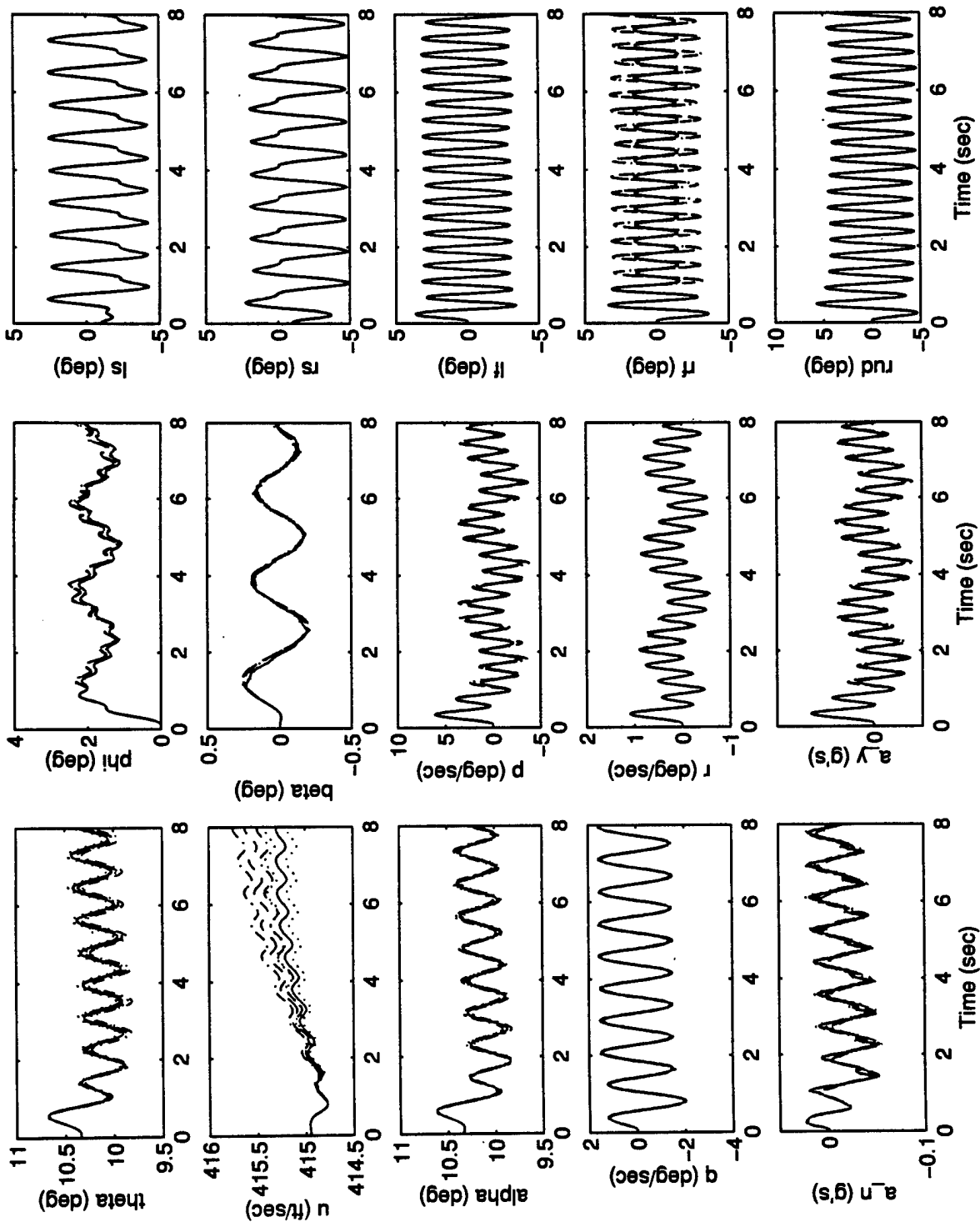
FULLY FUNCTIONAL AIRCRAFT
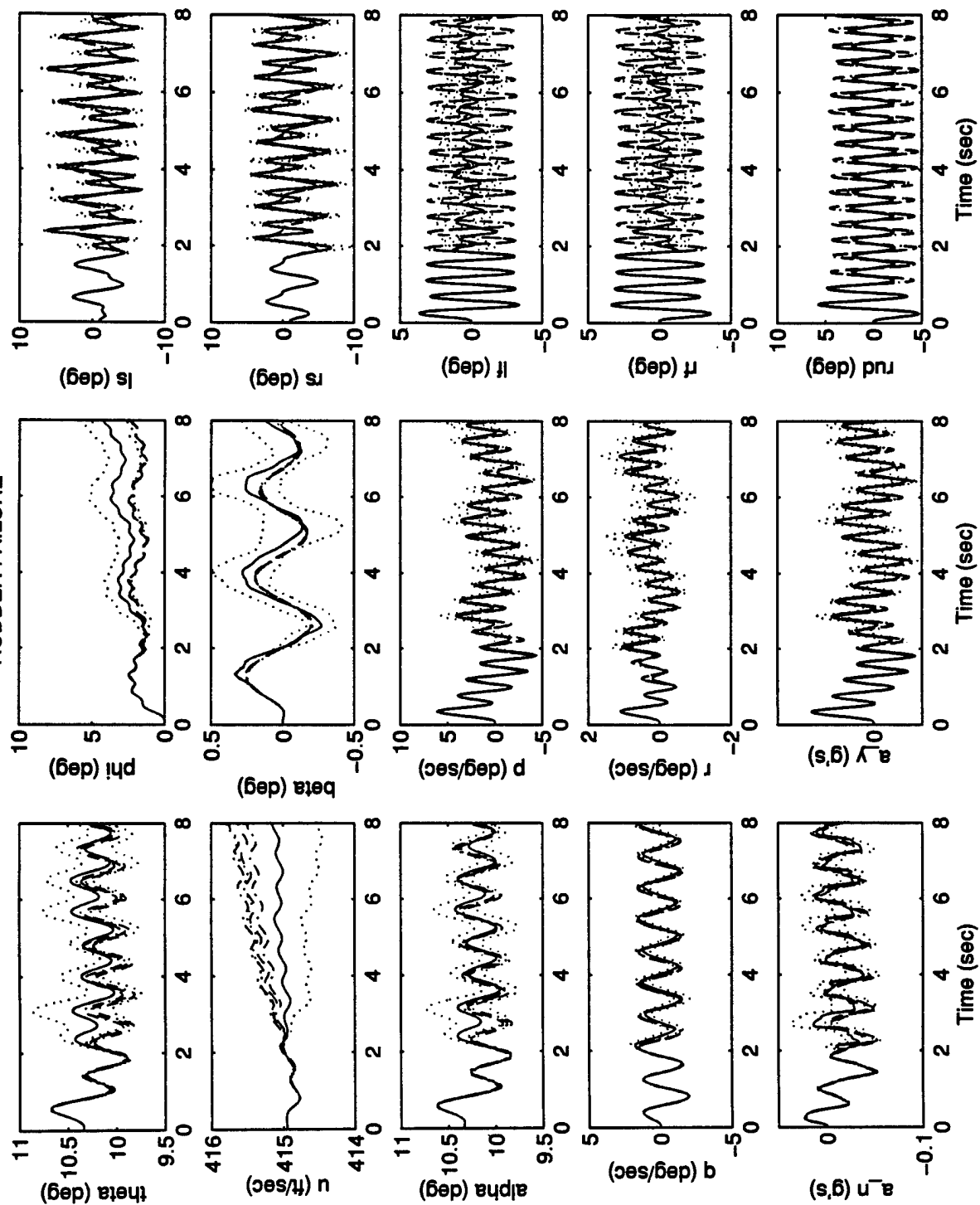
LEFT STABILATOR FAILURE

RIGHT STABILATOR FAILURE

LEFT FLAPERON FAILURE

RIGHT FLAPERON FAILURE

RUDDER FAILURE

Appendix H.1: State Plots For Dual, Total Actuator (ε = 0) and Total-Actuator / Total -Sensor

Impairments, Control Redistribution 'ON', Dither 'ON', No Maneuvers

This appendix contains the state plots for "total actuator / total actuator" and "total actuator / total sensor" dual impairment scenarios, *with* Control Reconfiguration (Redistribution) and with control dithering (Section 4.11.3 and Appendix D.1). The first impairment is inserted at 1 second, followed by the second impairment at 2 seconds, and in all cases, there is no aircraft maneuvering. Table H.1 on the following page lists the impairment cases, by case number, which are to be found in this appendix. The leftmost column of Table H.1 represents the first impairment occurring at 1 second, while the top row represents the second impairment occurring at 2 seconds. The table entries list the failure codes found in the plot titles for the failure case represented by the table row and column. **Bold** entries correspond to cases of no second impairment. As an example, the entry for a left stabilator (LS) impairment at 1 second, followed by a right flaperon (RF) impairment at 2 seconds is found in entry '(LS, RF)' in the table, and the corresponding failure case is 'fail01.04'. The state plot will contain this code ('fail01.04') in the plot title. In fact, for this specific case, the plot title is: "dual-failure fail01.04 with reconfiguration". The reader should *not* be confused by the fact that, for cases of total sensor second impairments, there is an extra set of zeroes (example: 'fail001.006' vs. 'fail01.06', as one may anticipate) in the failure code. The dual, *total* actuator impairment cases were run at an earlier date, before the additional, zero placeholders were added to the plotting routine to provide for meaningful plot titles during *partial* impairment scenarios to come. Each page of State Plots in this appendix contains three columns of five plots and corresponds to one impairment condition, or test point. The first column shows the aircraft longitudinal states and normal acceleration (a_n). Column two shows lateral-directional states and lateral acceleration (a_y). The third column, of most interest to us, displays actuator positions (not commands). Two actual time histories, the result of a 10-run Monte Carlo simulation of each impairment condition, are plotted on each of the 15 subplots. The first time history, a "dashed / dashed-dotted" trace, represents the "mean ± one standard deviation" of the *fully functional* aircraft response. The second time history is a "solid line / dotted" trace and represents the response of the *impaired* aircraft at the given impairment condition.

Two impairment cases deserve special attention. It is observed that 'fail02.03', a case of a total right stabilator impairment followed by a total *left* flaperon impairment, and 'fail02.04', a total right stabilator followed by total *right* flaperon impairment, do not display similar actuator position traces as one might expect. While an examination of Appendix D.1 reveals that MMAE detects each impairment exceptionally well in each case, it is apparent that the Control Reconfiguration solution is noticeably different. The exact reason for this could not be determined due to a time shortage, but it is strongly suspected that the reason lies in the "two stage" method chosen to implement Control Reconfiguration under conditions of dual impairments (Section 4.8). (This was the reason that the strong recommendation was made in Chapter 5 to implement full pseudoinverse calculations, in future research, to eliminate confusing "shortcuts" and to guarantee uniformity of results between research efforts.)

Second Impairment

	LS (100%)	RS (100%)	LF (100%)	RF (100%)	RUD (100%)	AOA (100%)	Q (100%)	A_n (100%)	P (100%)	R (100%)	A_y (100%)
LS (100%)	**fail01.00**	fail01.02	fail01.03	fail01.04	fail01.05	fail001.006	fail001.007	fail001.008	fail001.009	fail001.0010	fail001.0011
RS (100%)	fail02.01	**fail02.00**	fail02.03	fail02.04	fail02.05	fail002.006	fail002.007	fail002.008	fail002.009	fail002.0010	fail002.0011
LF (100%)	fail03.01	fail03.02	**fail03.00**	fail03.04	fail03.05	fail003.006	fail003.007	fail003.008	fail003.009	fail003.0010	fail003.0011
RF (100%)	fail04.01	fail04.02	fail04.03	**fail04.00**	fail04.05	fail004.006	fail004.007	fail004.008	fail004.009	fail004.0010	fail004.0011
RUD (100%)	fail05.01	fail05.02	fail05.03	fail05.04	**fail05.00**	fail005.006	fail005.007	fail005.008	fail005.009	fail005.0010	fail005.0011

Table H.1 A Listing of All State Plots Found in Appendix H.1 by Failure Case

dual-failure fail01.00 with reconfiguration
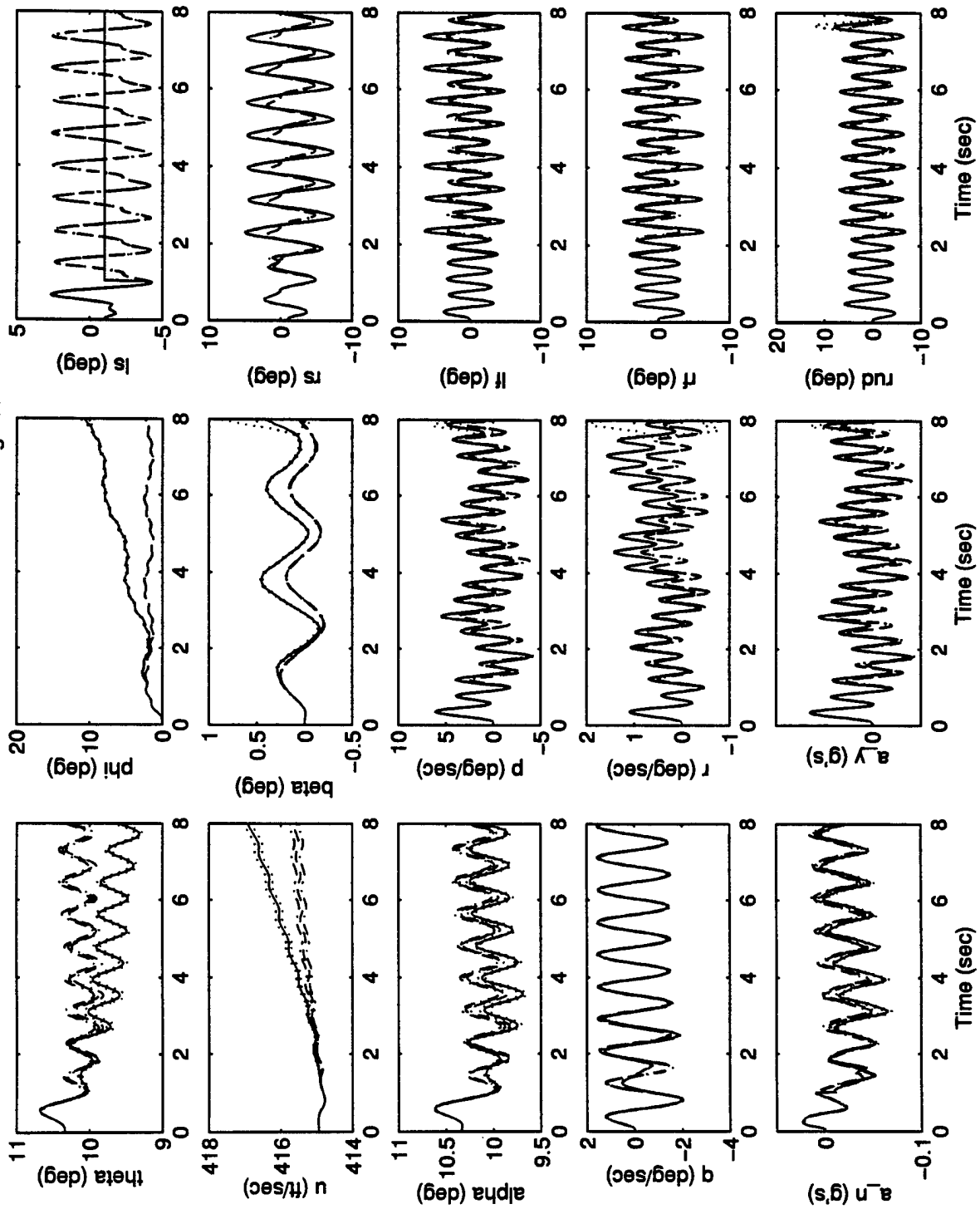
dual–failure fail01.02 with reconfiguration
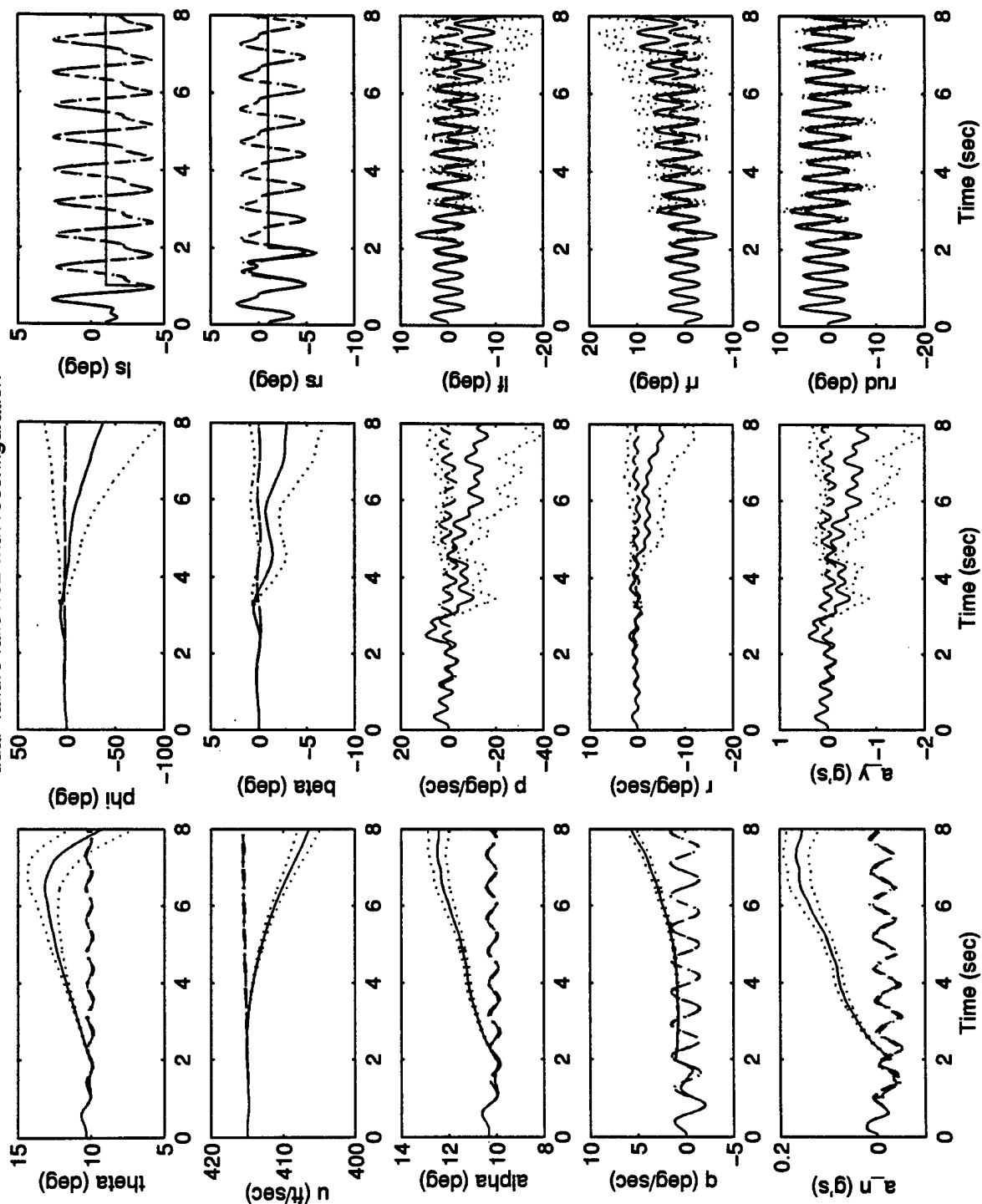
dual–failure fail01.03 with reconfiguration
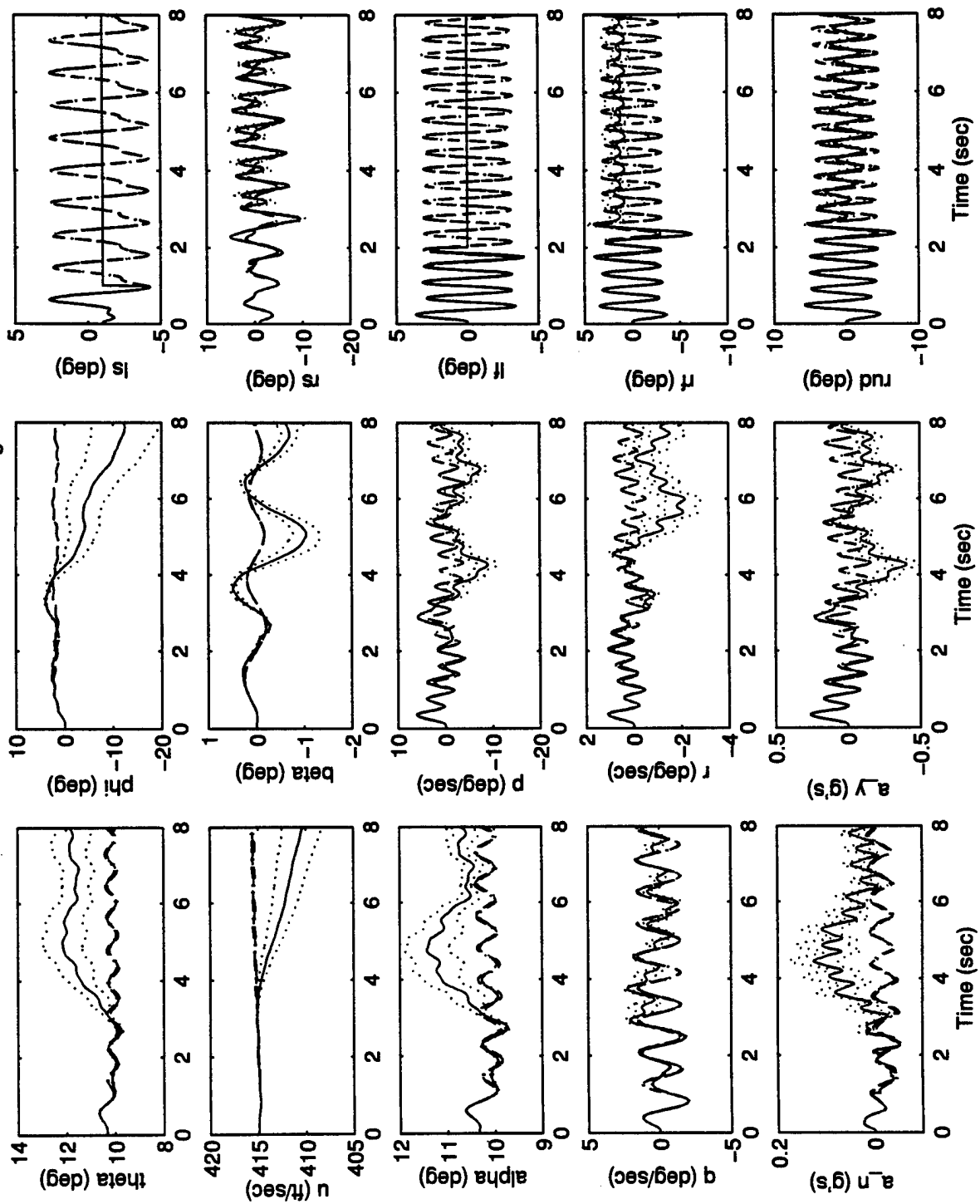
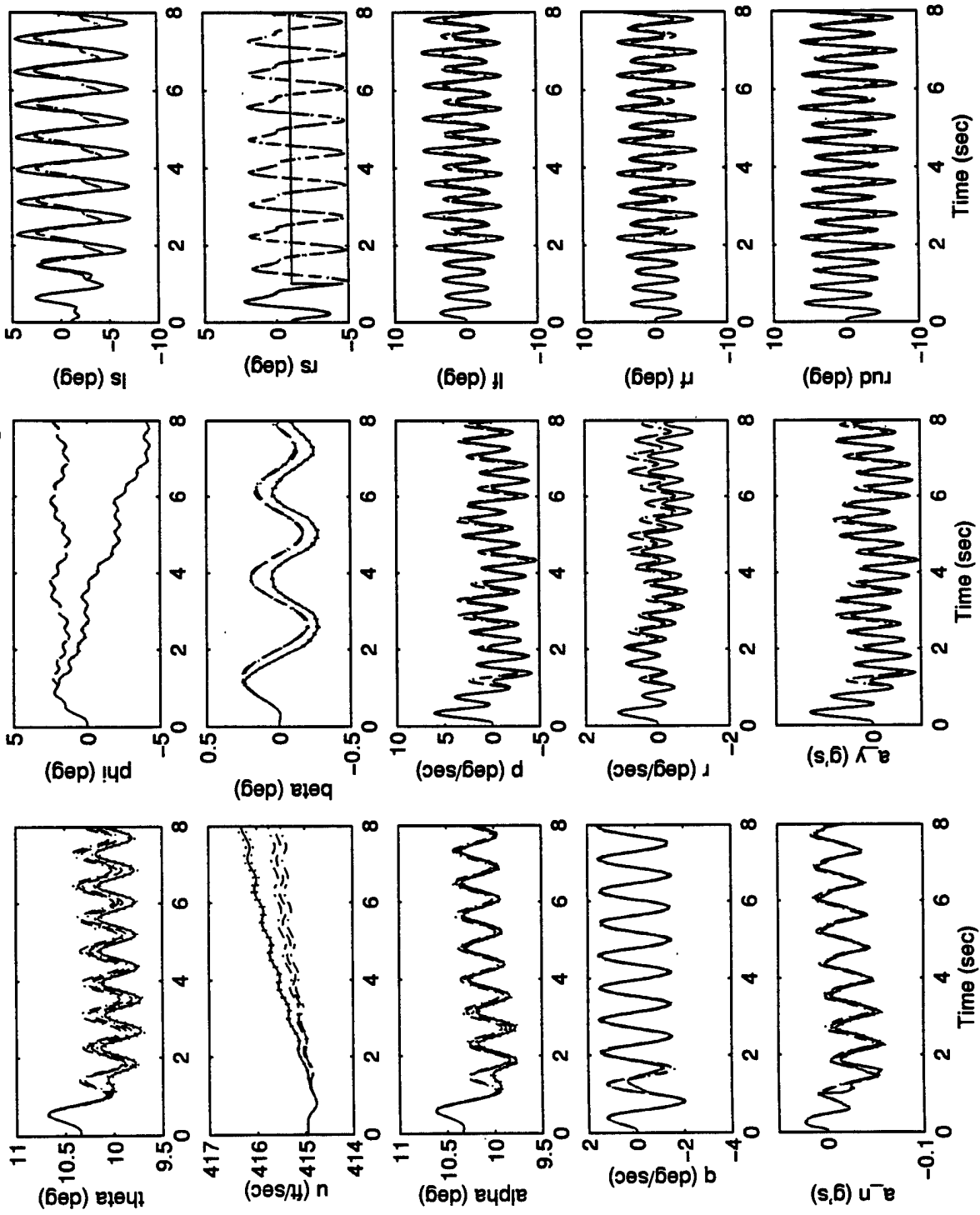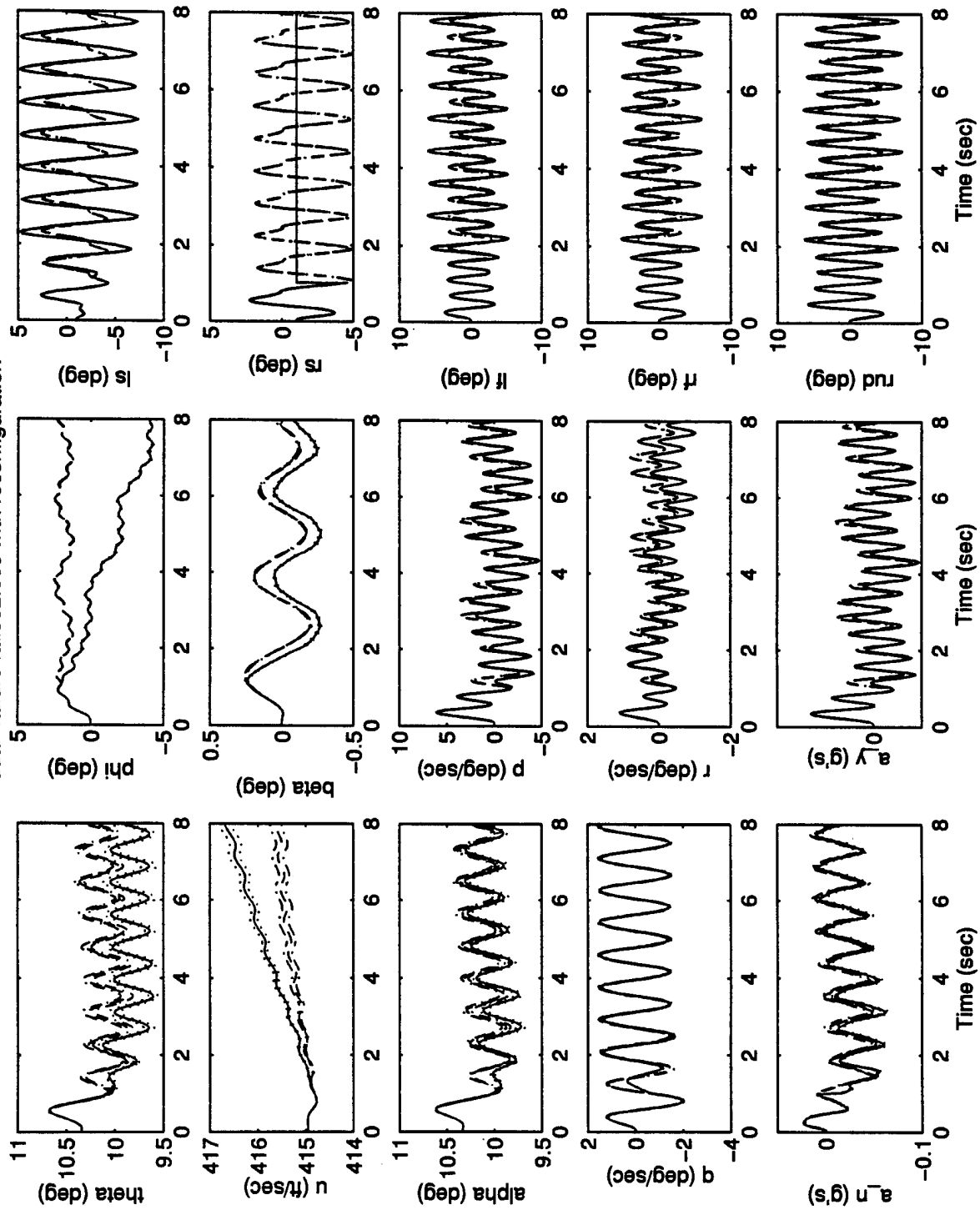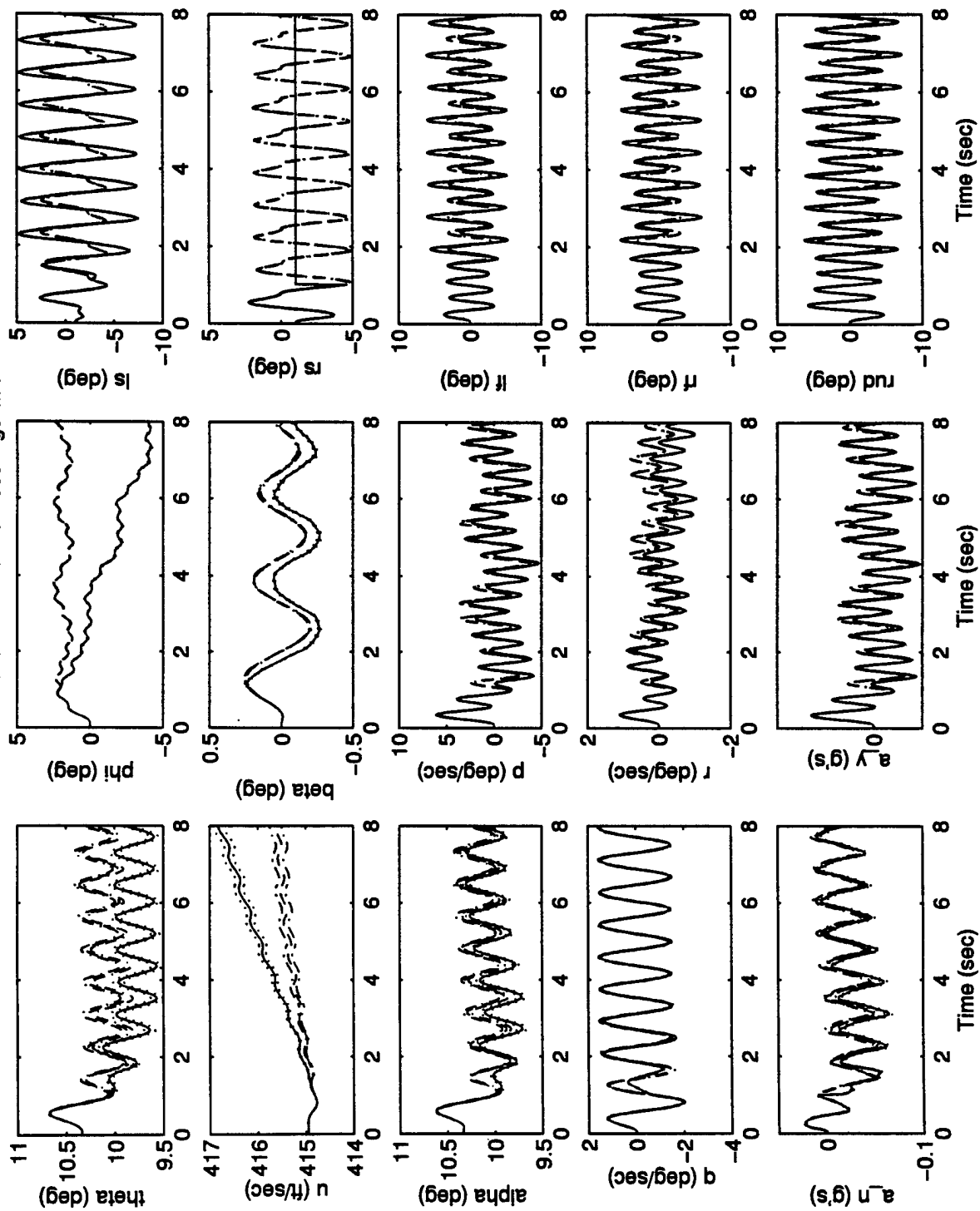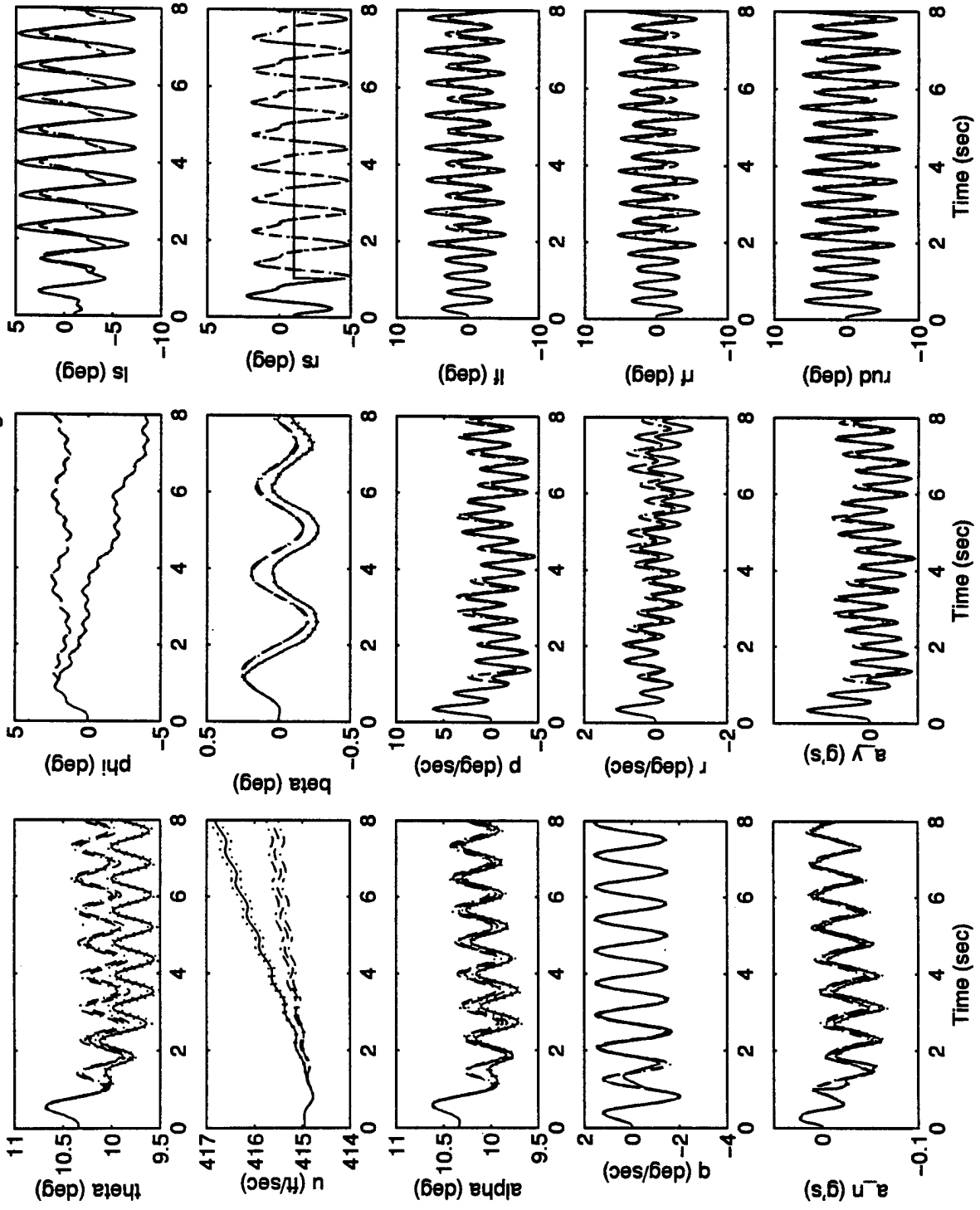dual-failure fail01.04 with reconfiguration
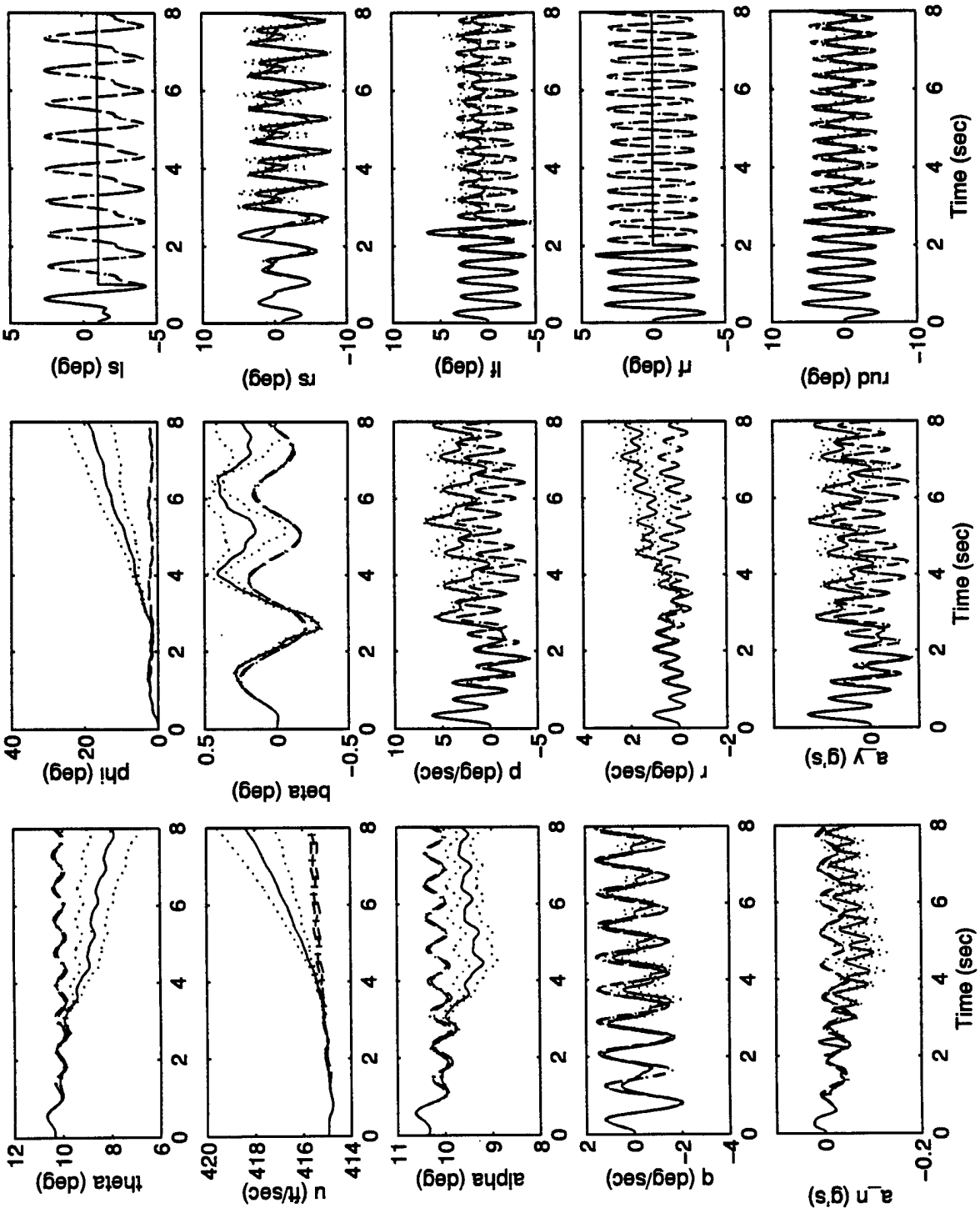
dual-failure fail01.05 with reconfiguration
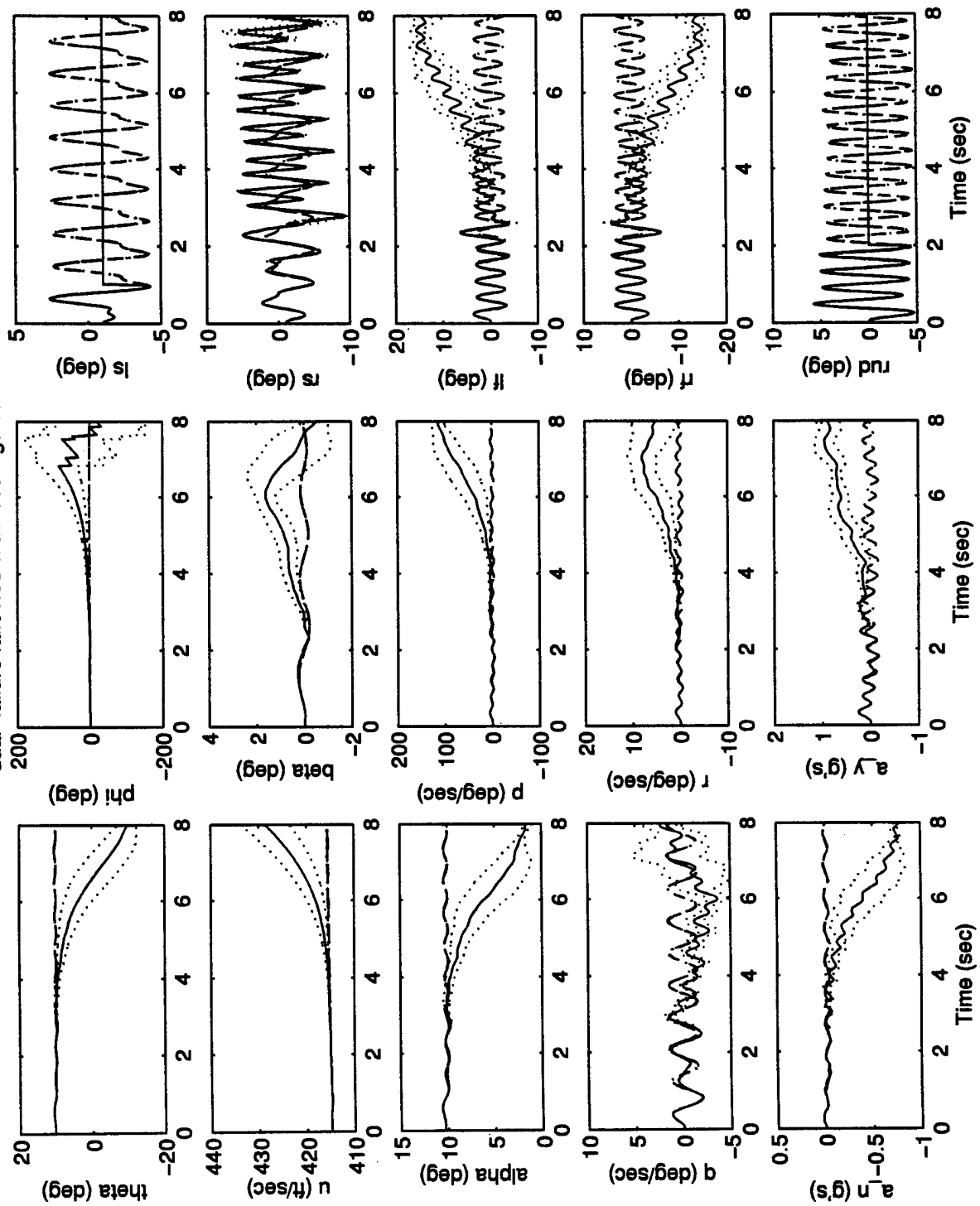
dual-failure fail001.006 with reconfiguration
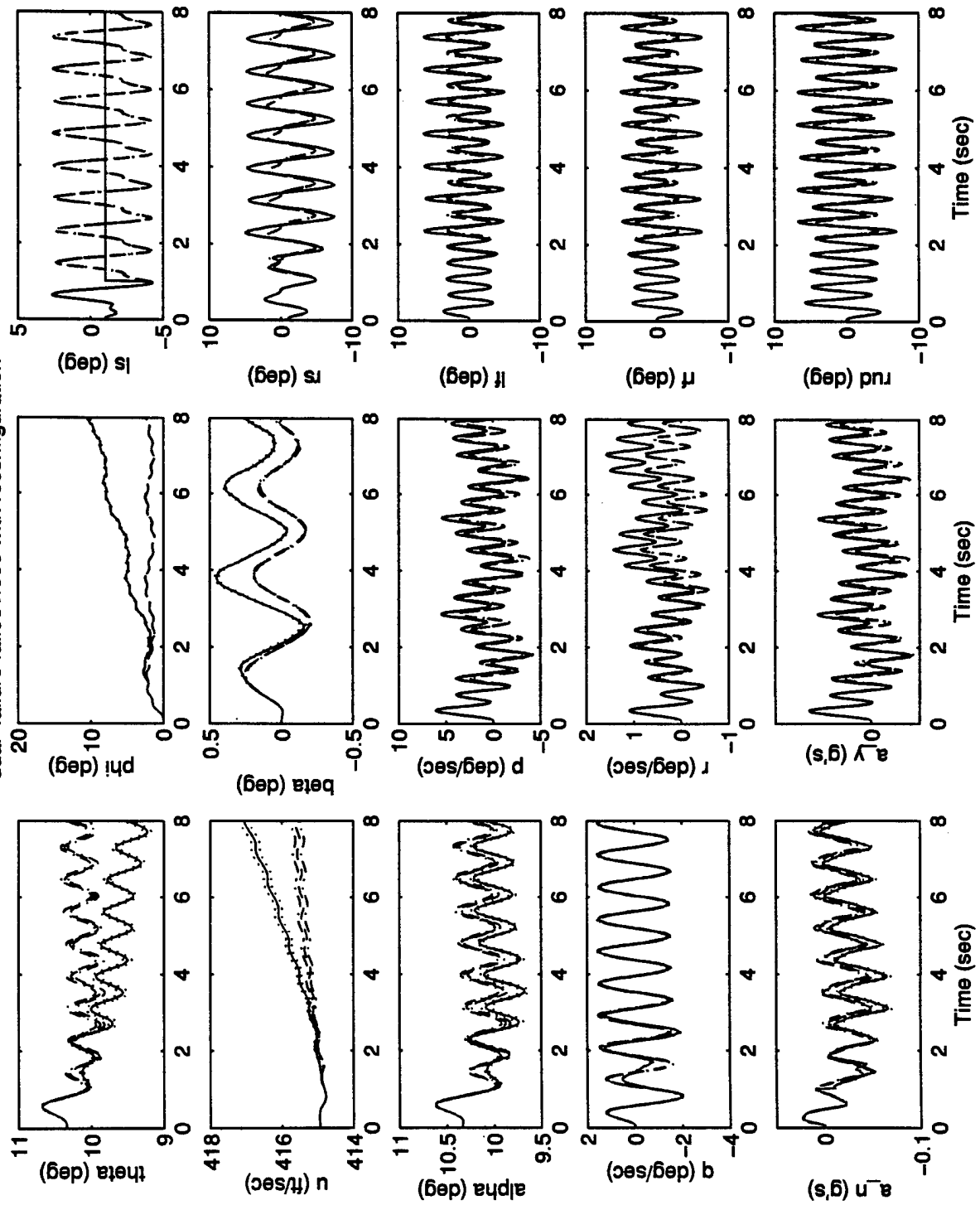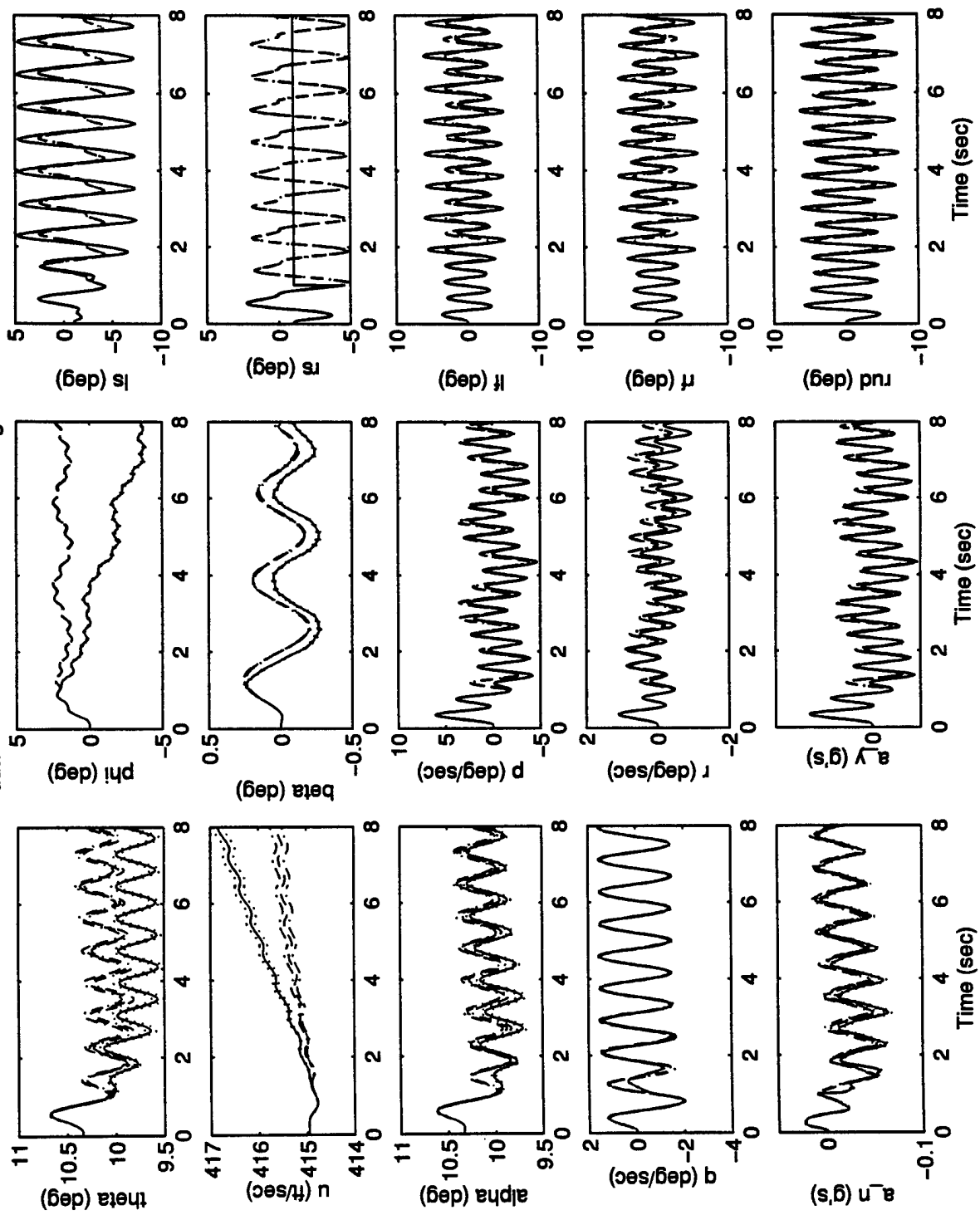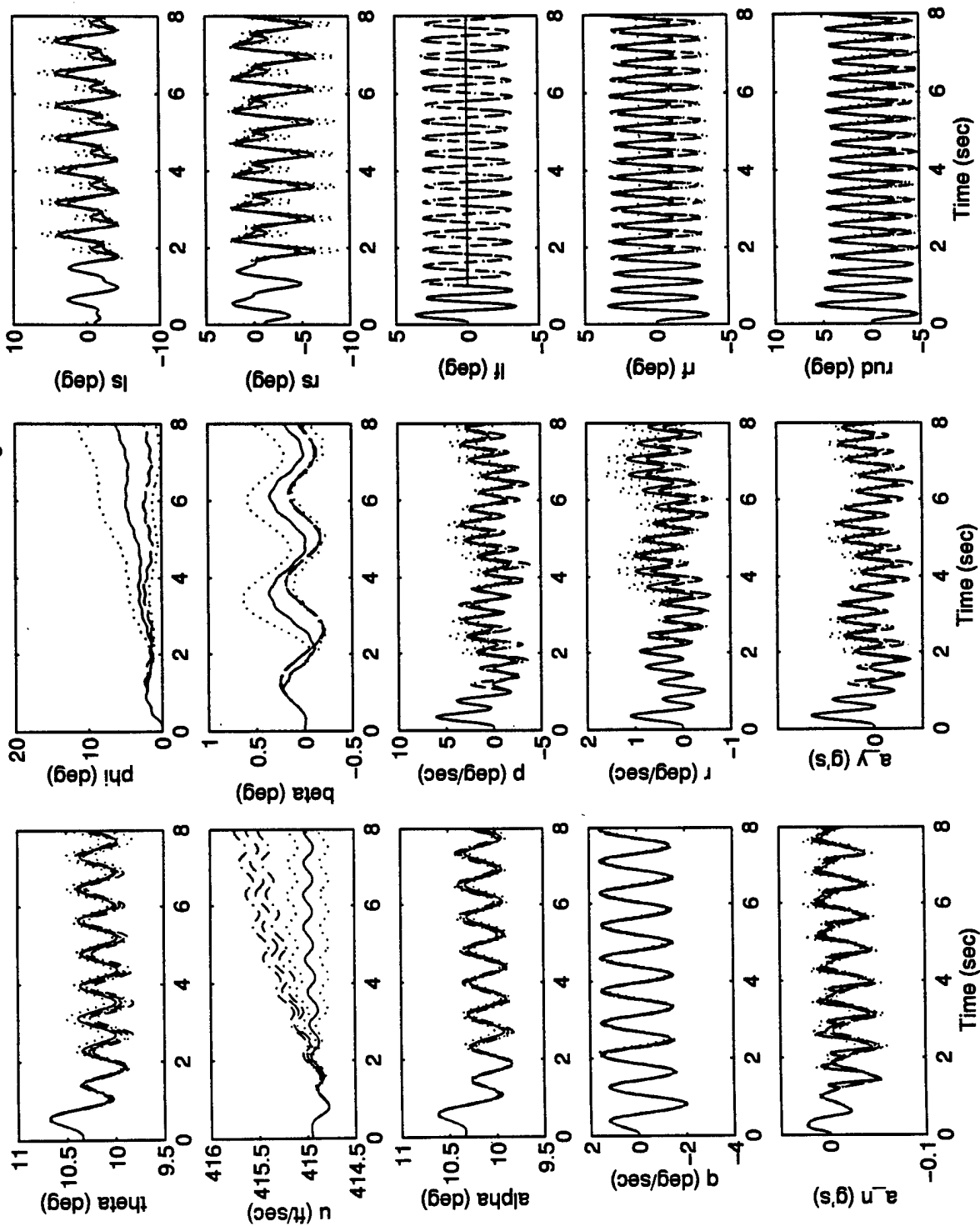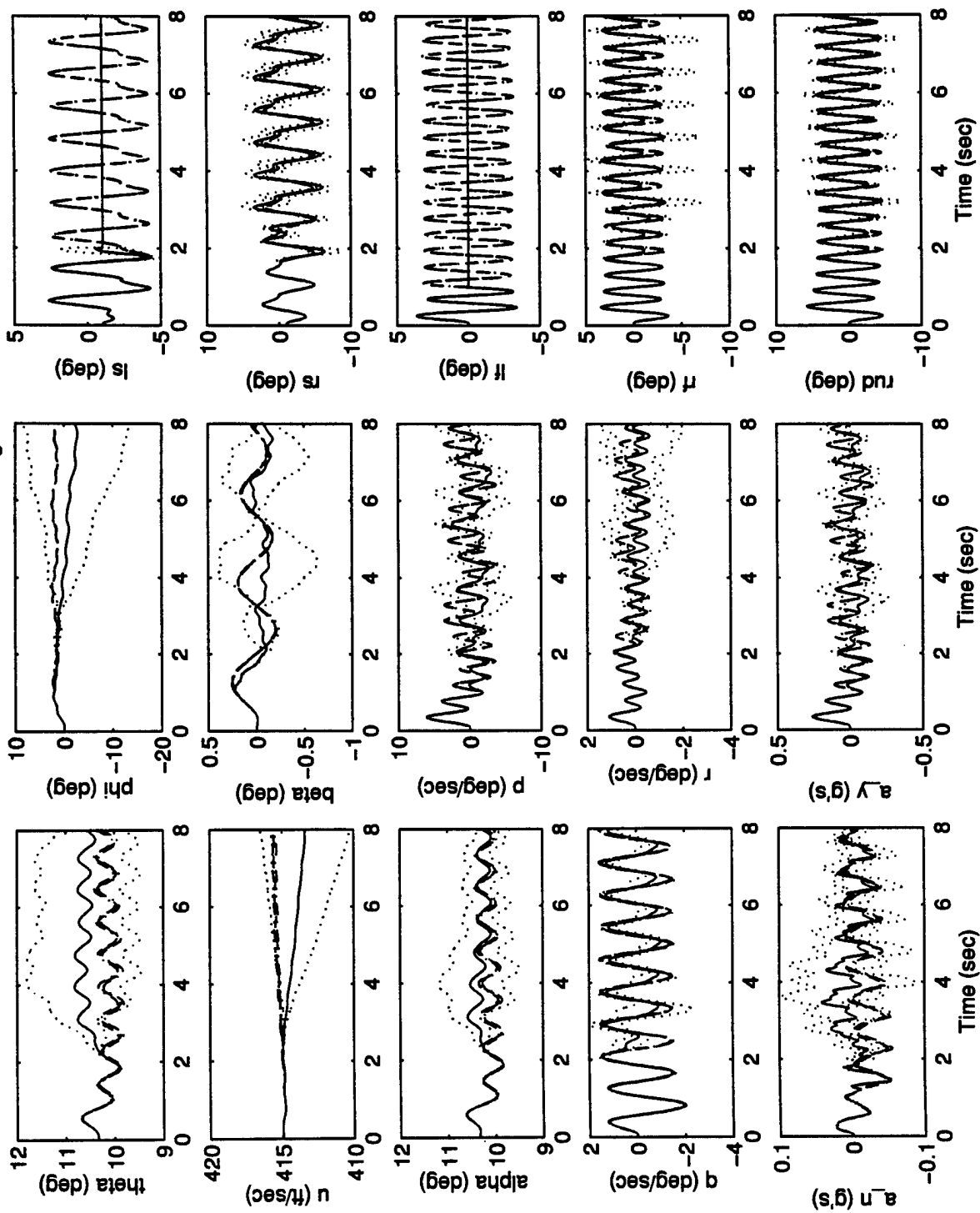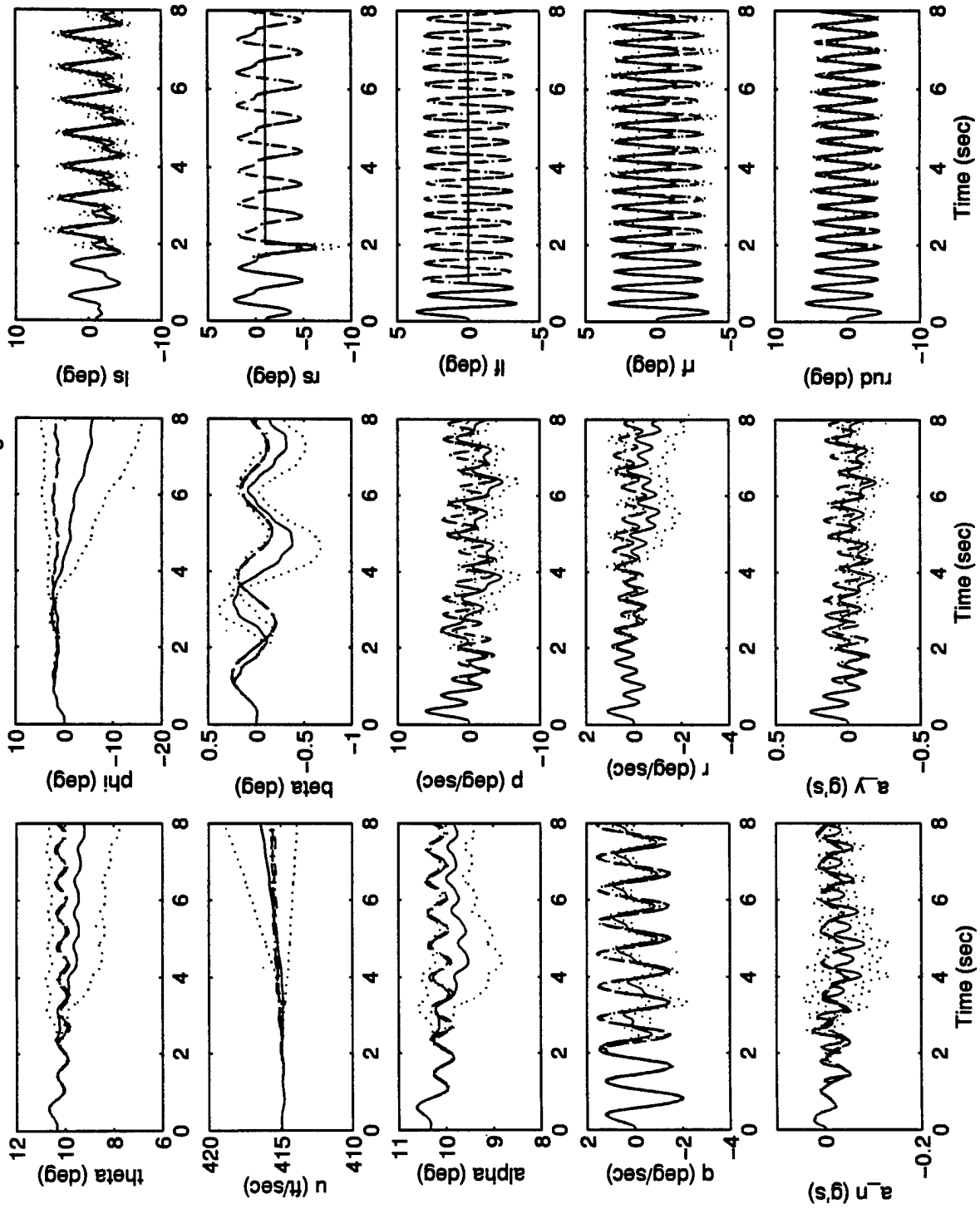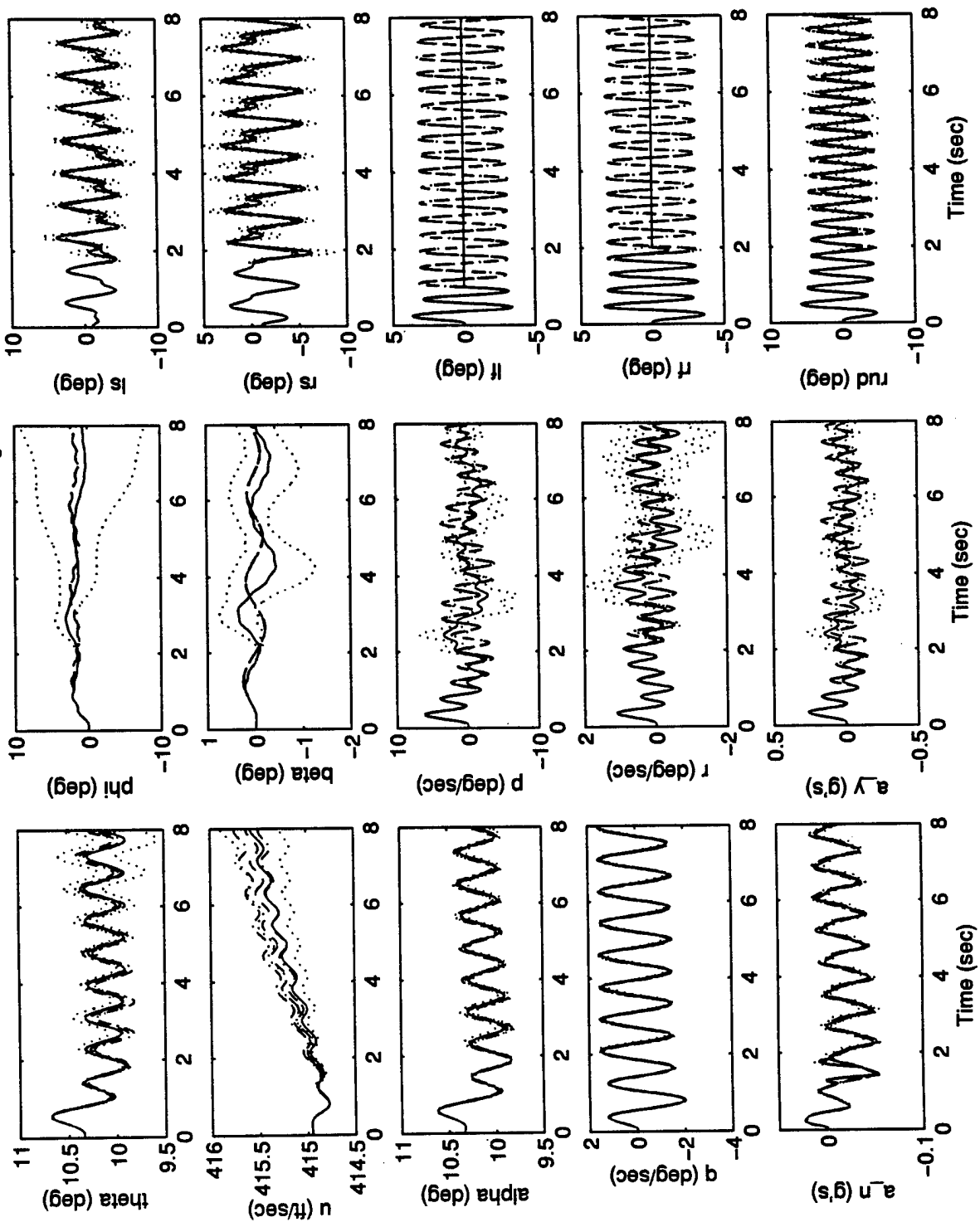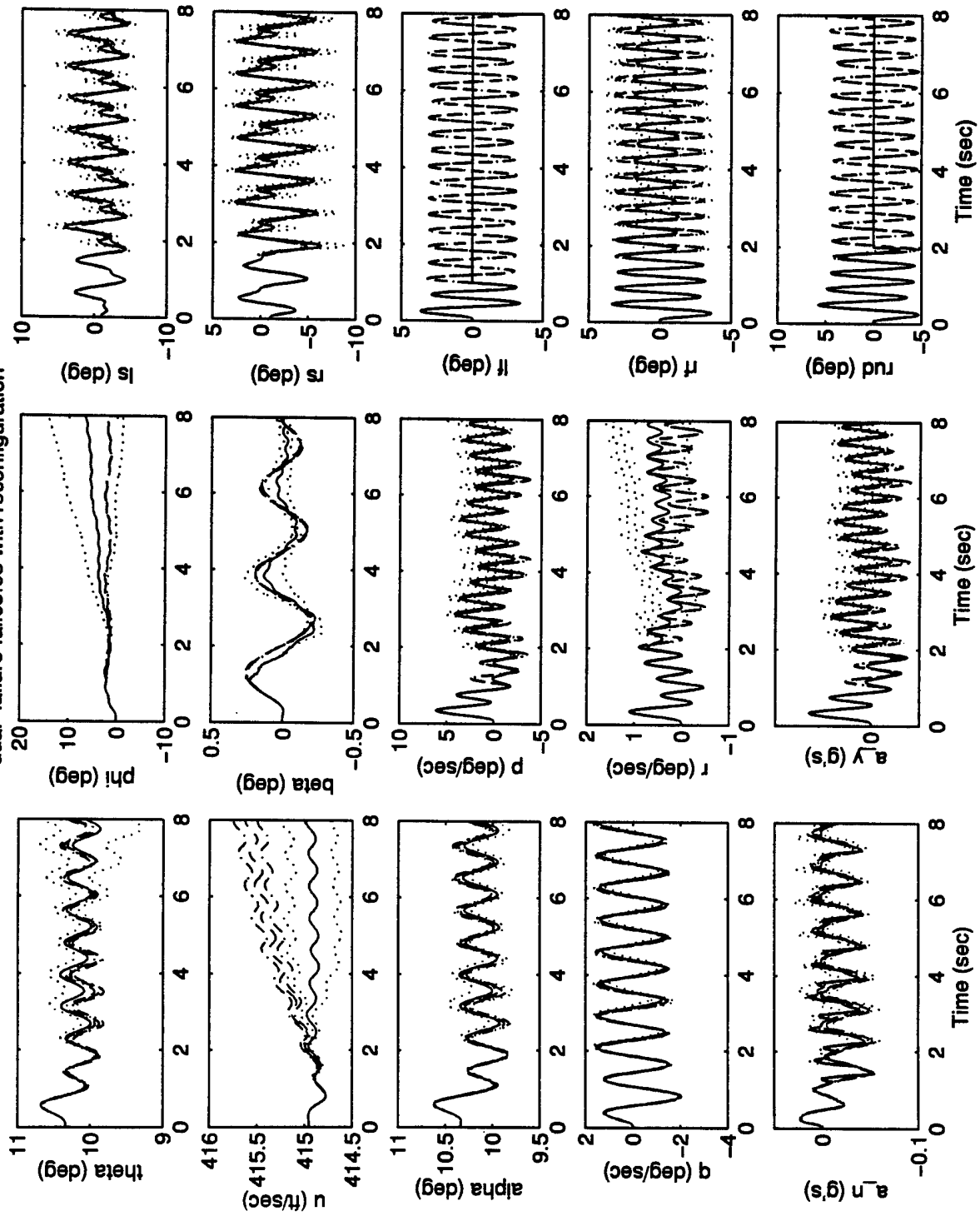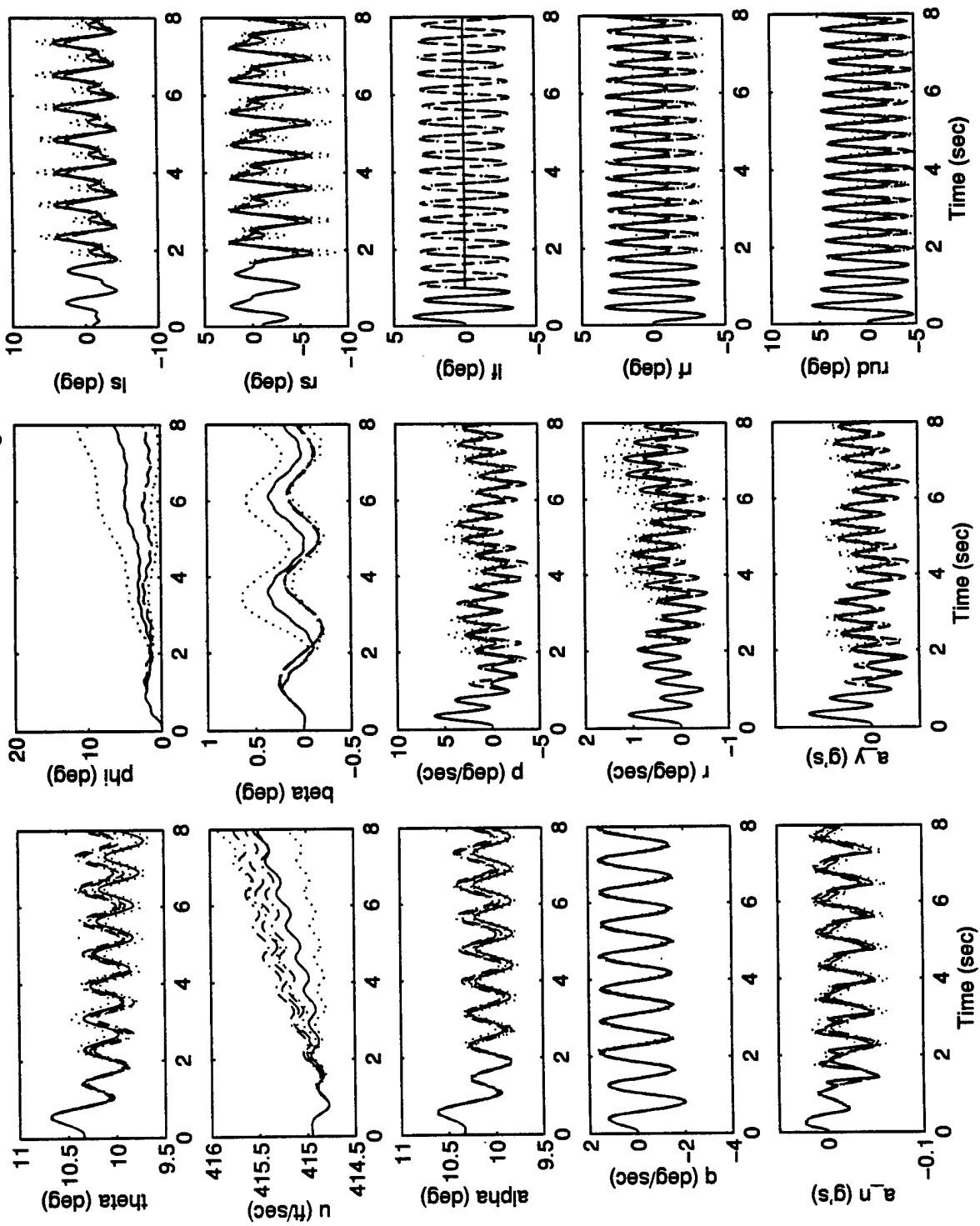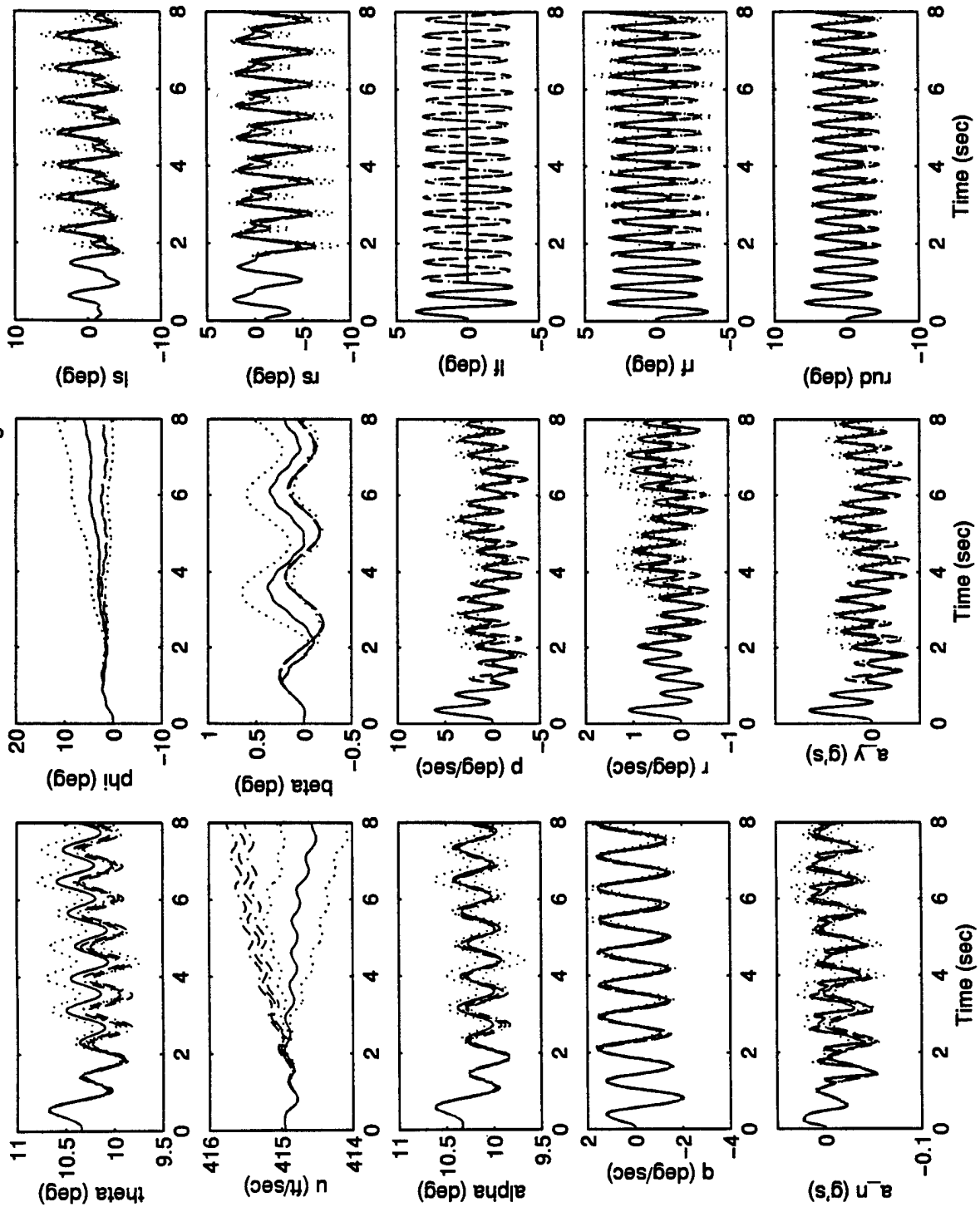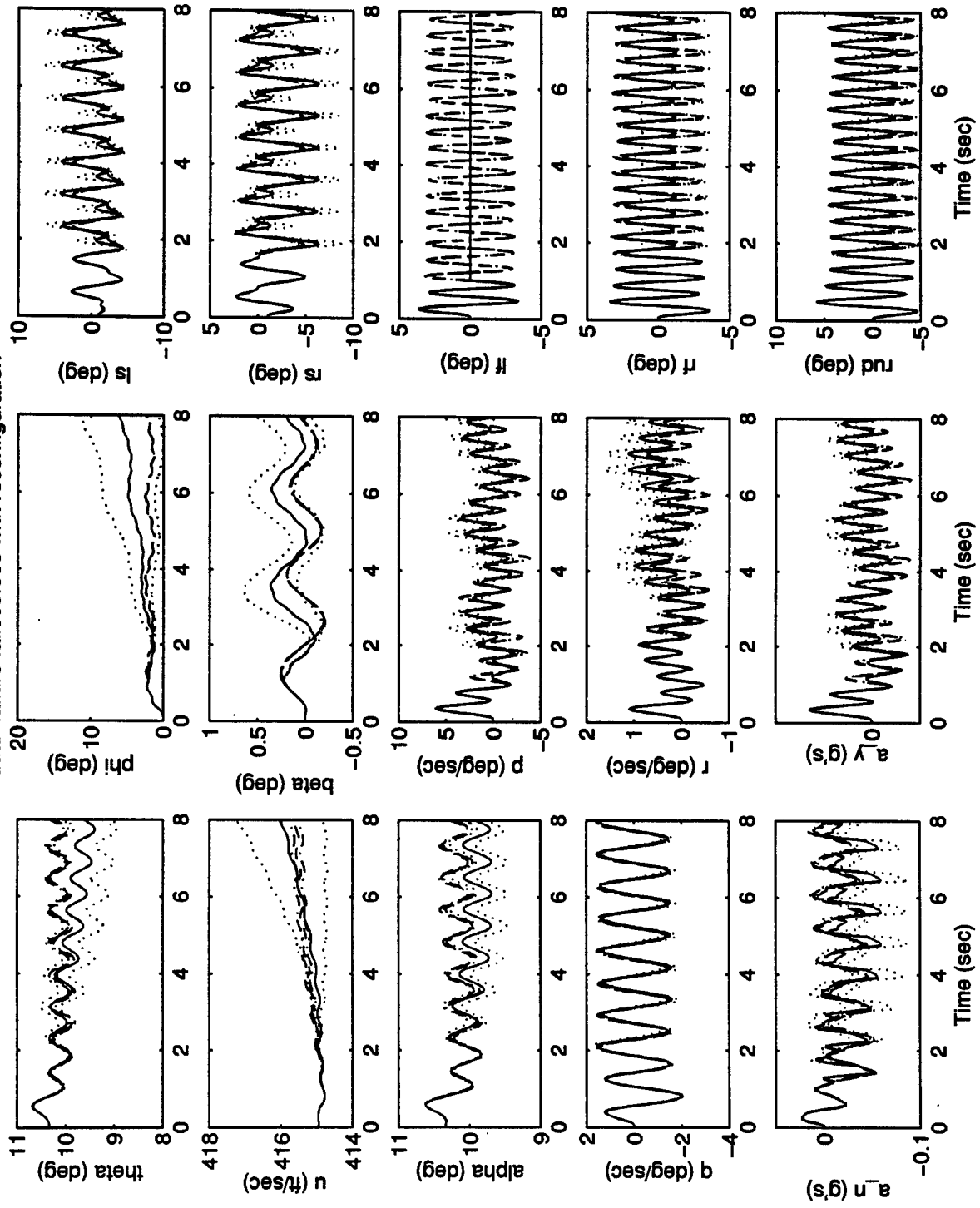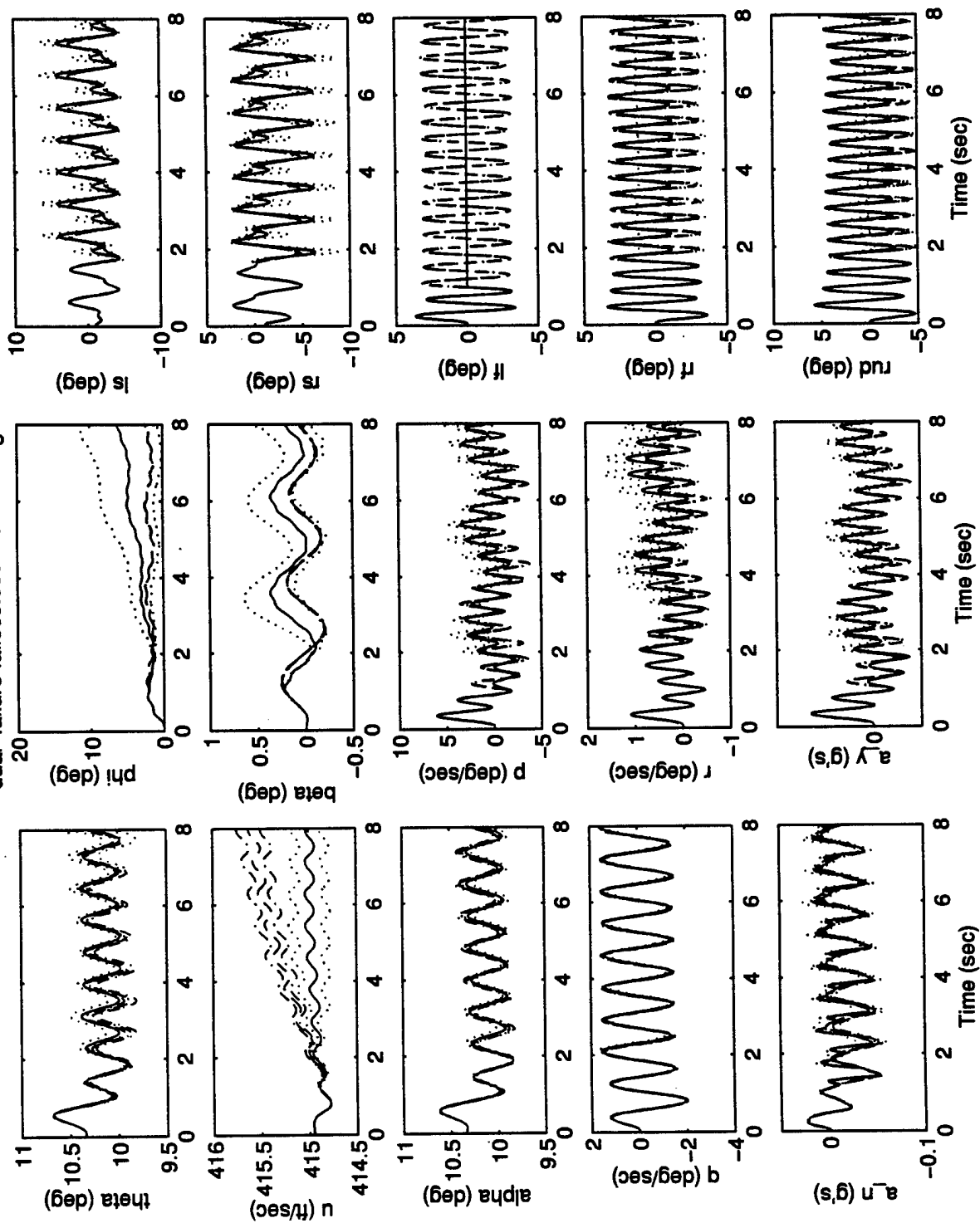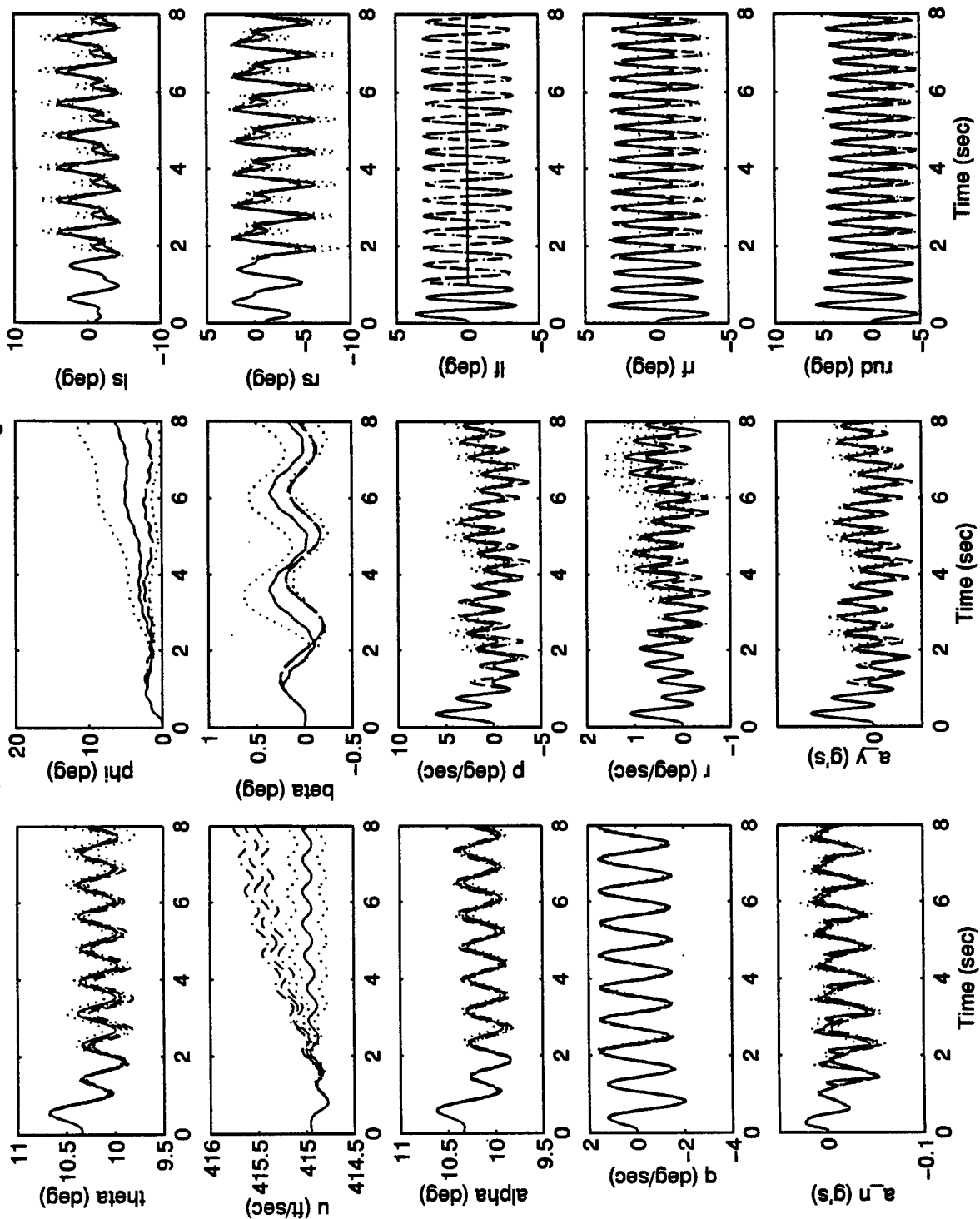
dual–failure fail001.007 with reconfiguration

ls (deg)
rs (deg)
lf (deg)
rf (deg)
rud (deg)

phi (deg)
beta (deg)
p (deg/sec)
r (deg/sec)
a_Y (g's)

theta (deg)
u (ft/sec)
alpha (deg)
q (deg/sec)
a_n (g's)

Time (sec)
Time (sec)
Time (sec)
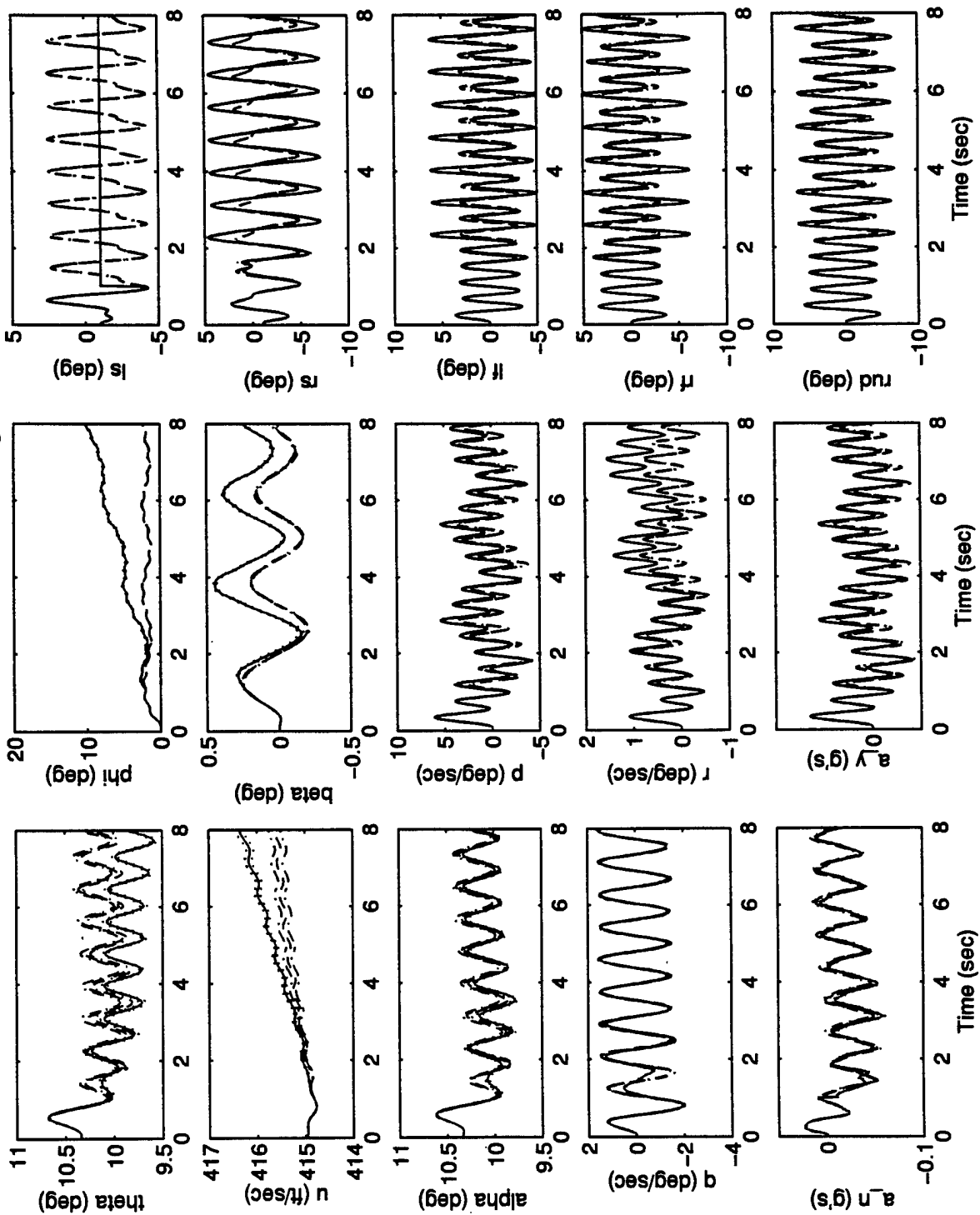
dual-failure fail001.008 with reconfiguration
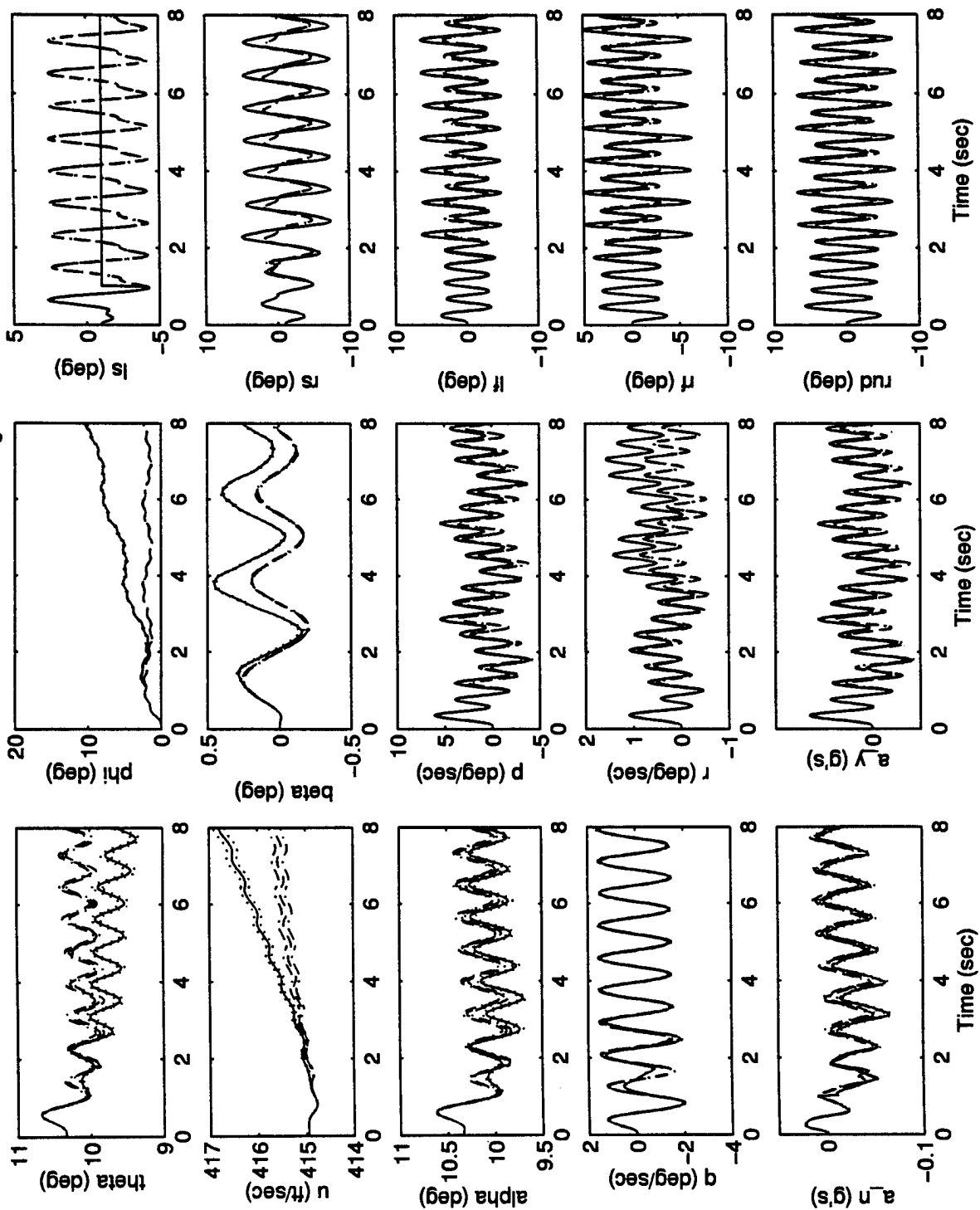
dual–failure fail001.009 with reconfiguration

ls (deg)
rs (deg)
lf (deg)
rf (deg)
rud (deg)

phi (deg)
beta (deg)
p (deg/sec)
r (deg/sec)
a_y (g's)

theta (deg)
u (ft/sec)
alpha (deg)
q (deg/sec)
a_n (g's)

Time (sec)
Time (sec)
Time (sec)
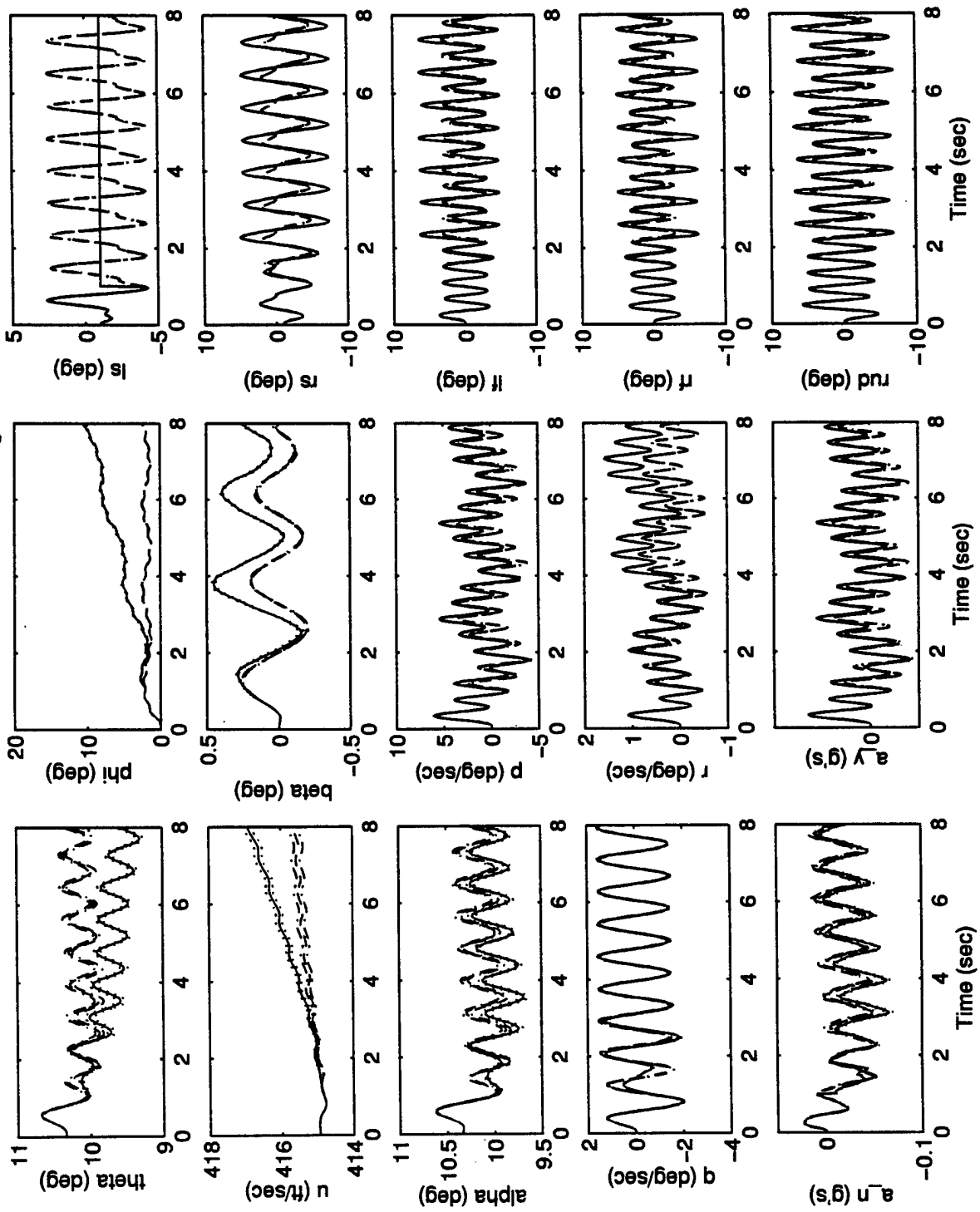
dual-failure fail001.0010 with reconfiguration

ls (deg) rs (deg) lf (deg) rf (deg) rud (deg)

phi (deg) beta (deg) p (deg/sec) r (deg/sec) a_y (g's)

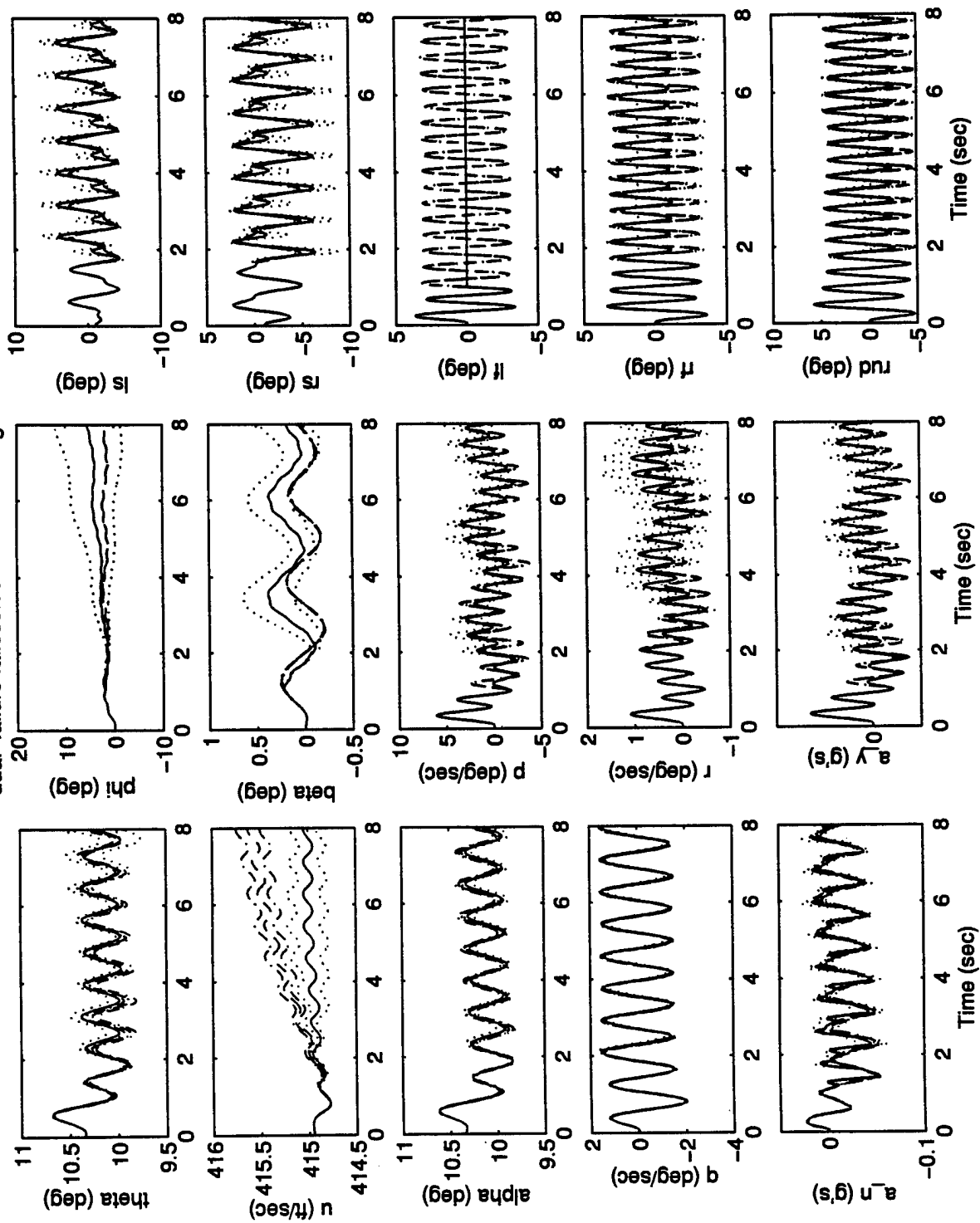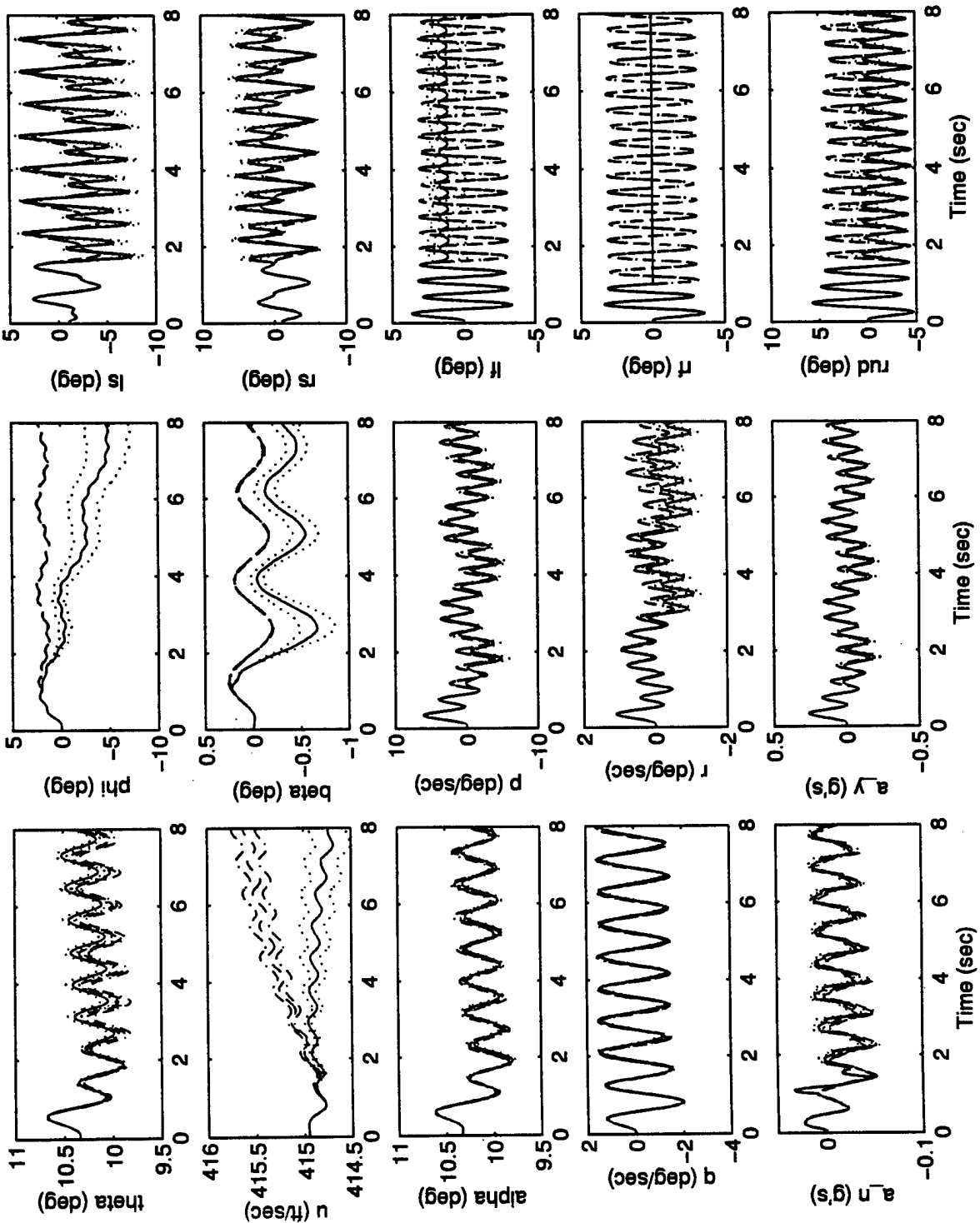theta (deg) u (ft/sec) alpha (deg) q (deg/sec) a_n (g's)
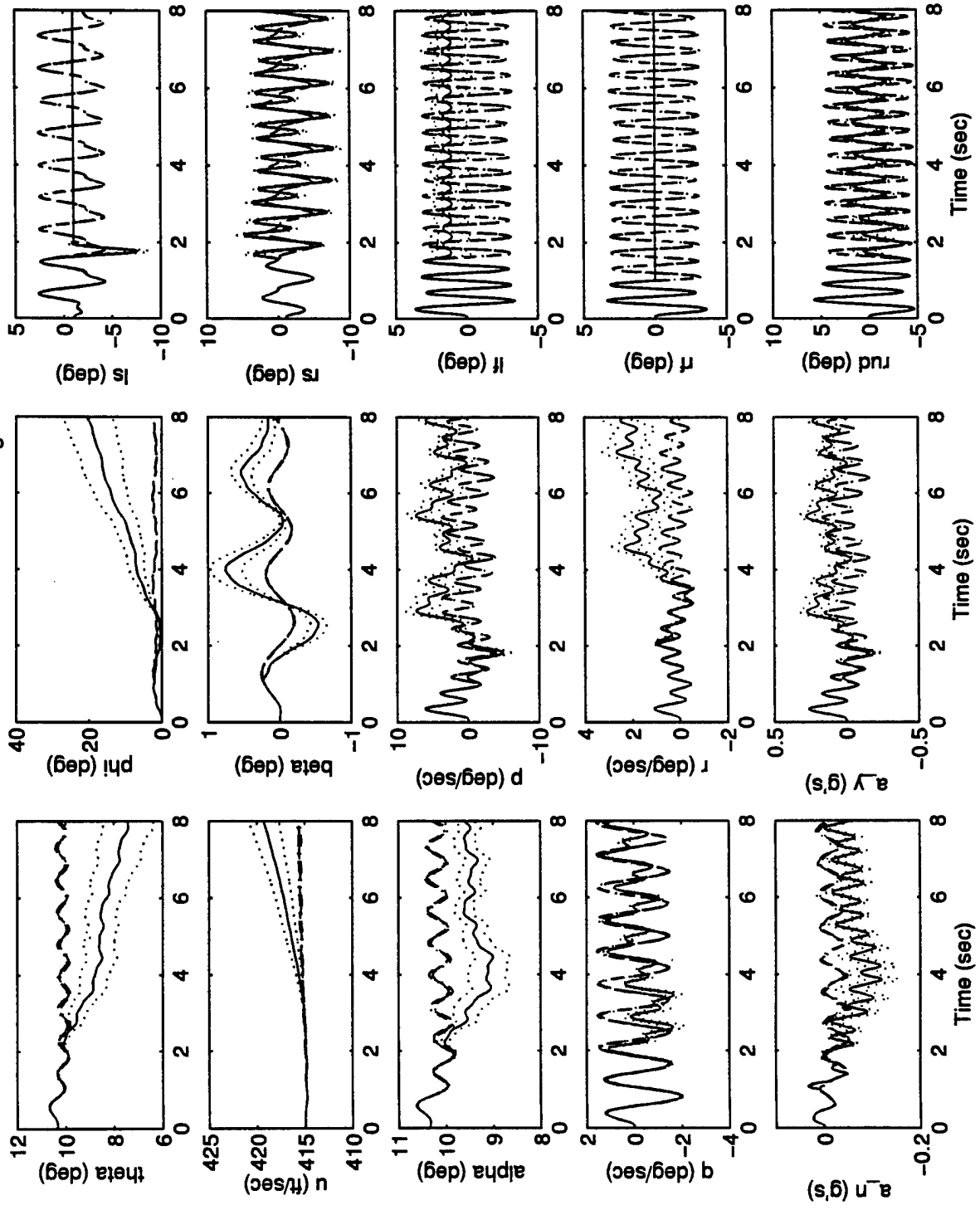
Time (sec)
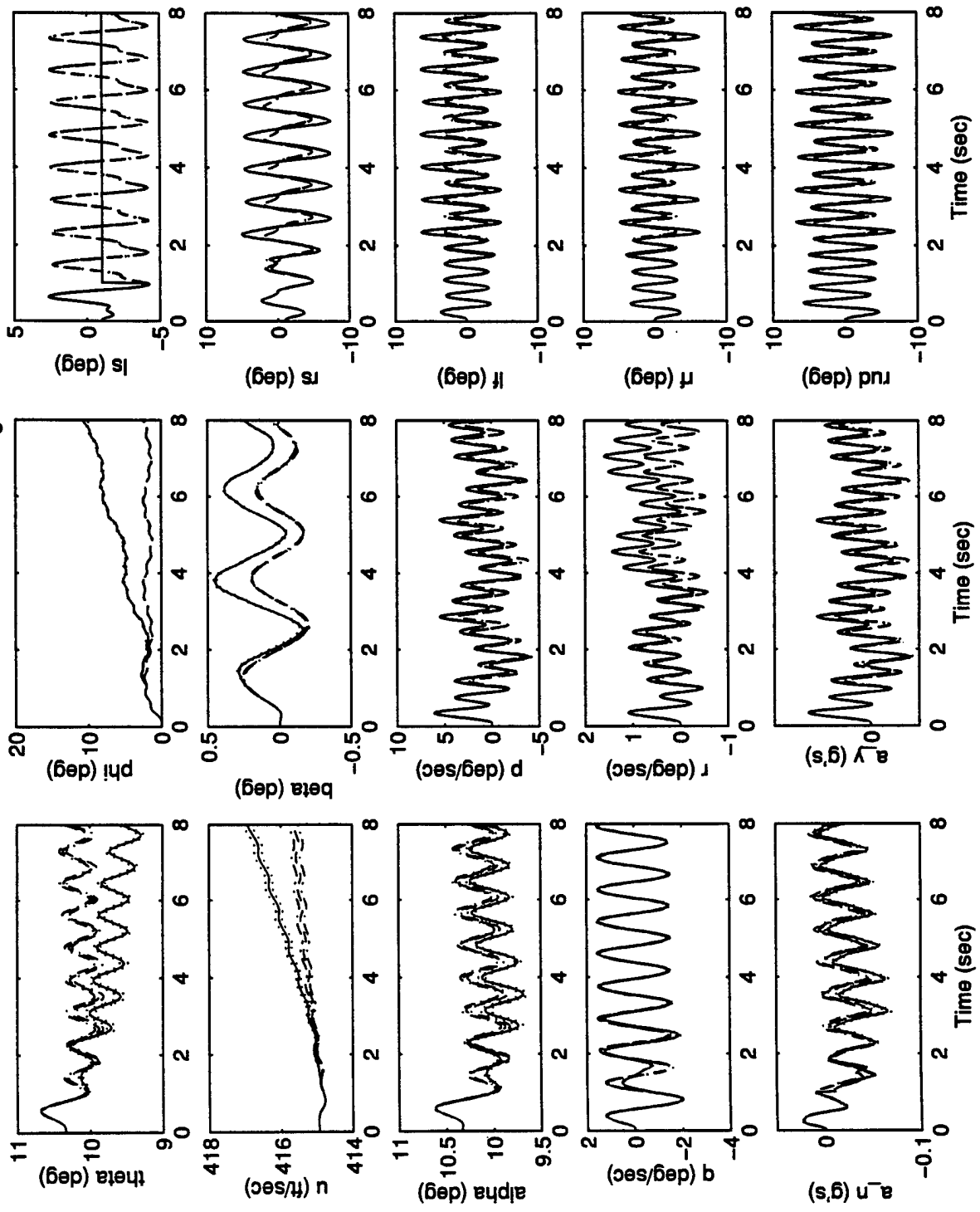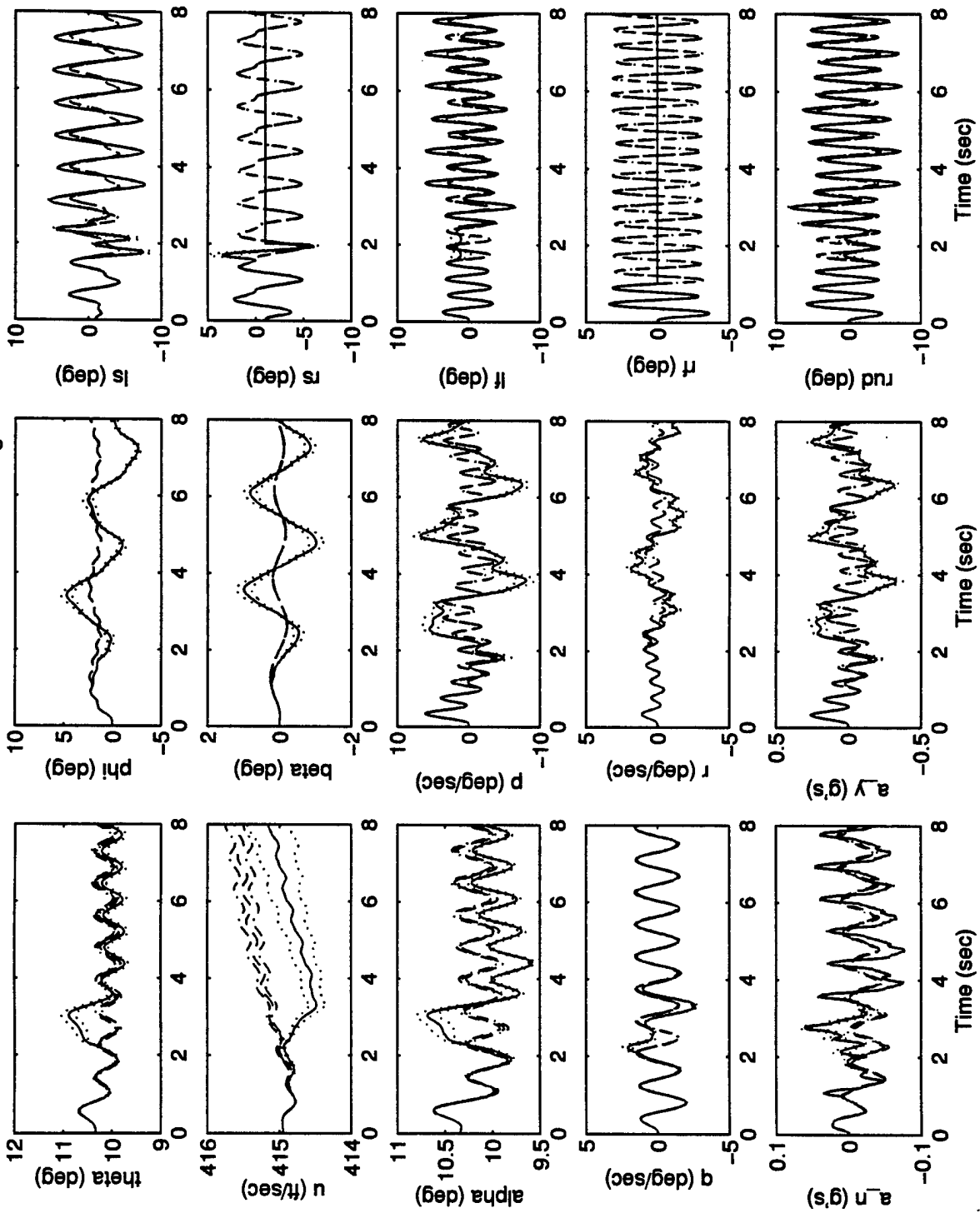
dual-failure fail001.0011 with reconfiguration
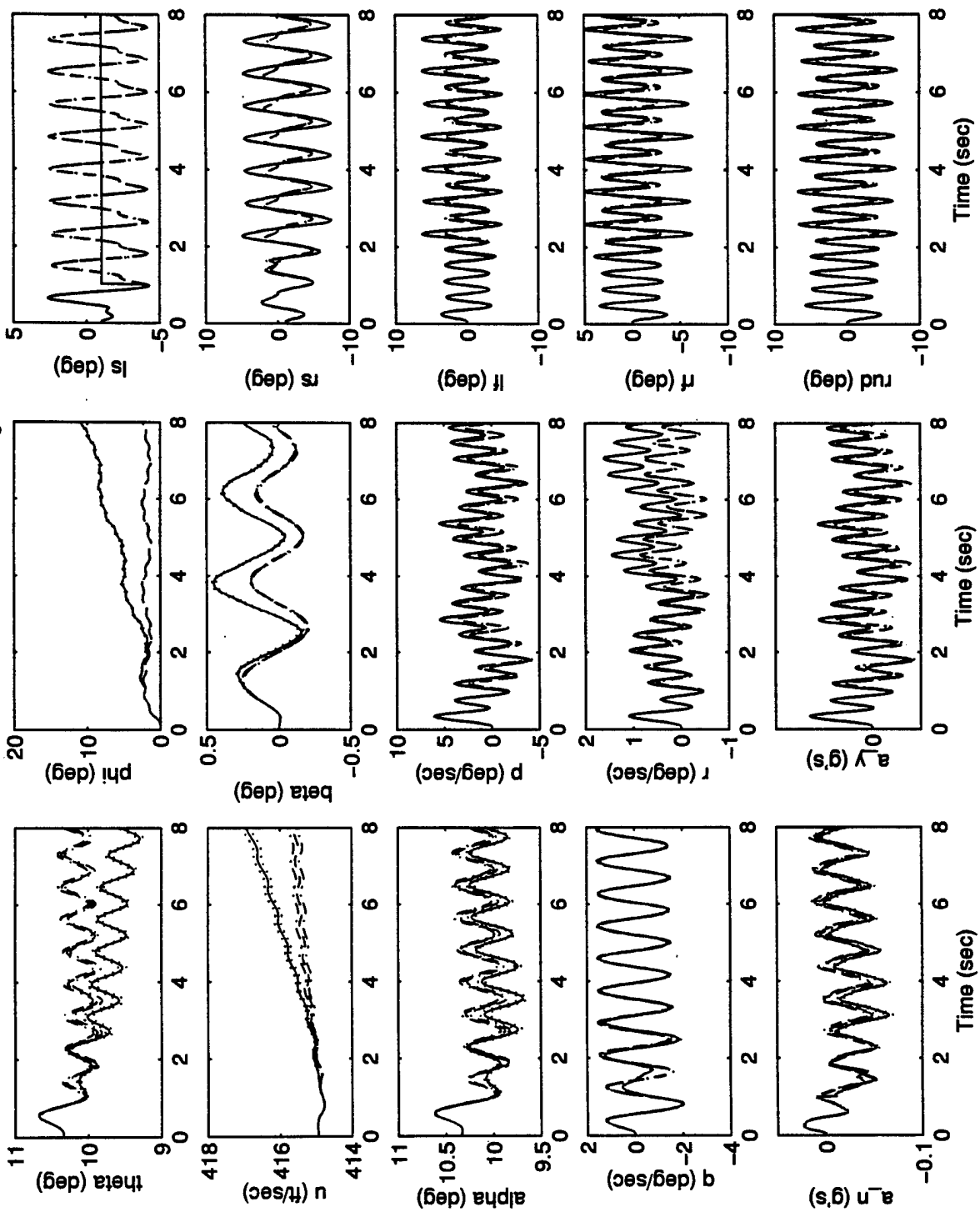
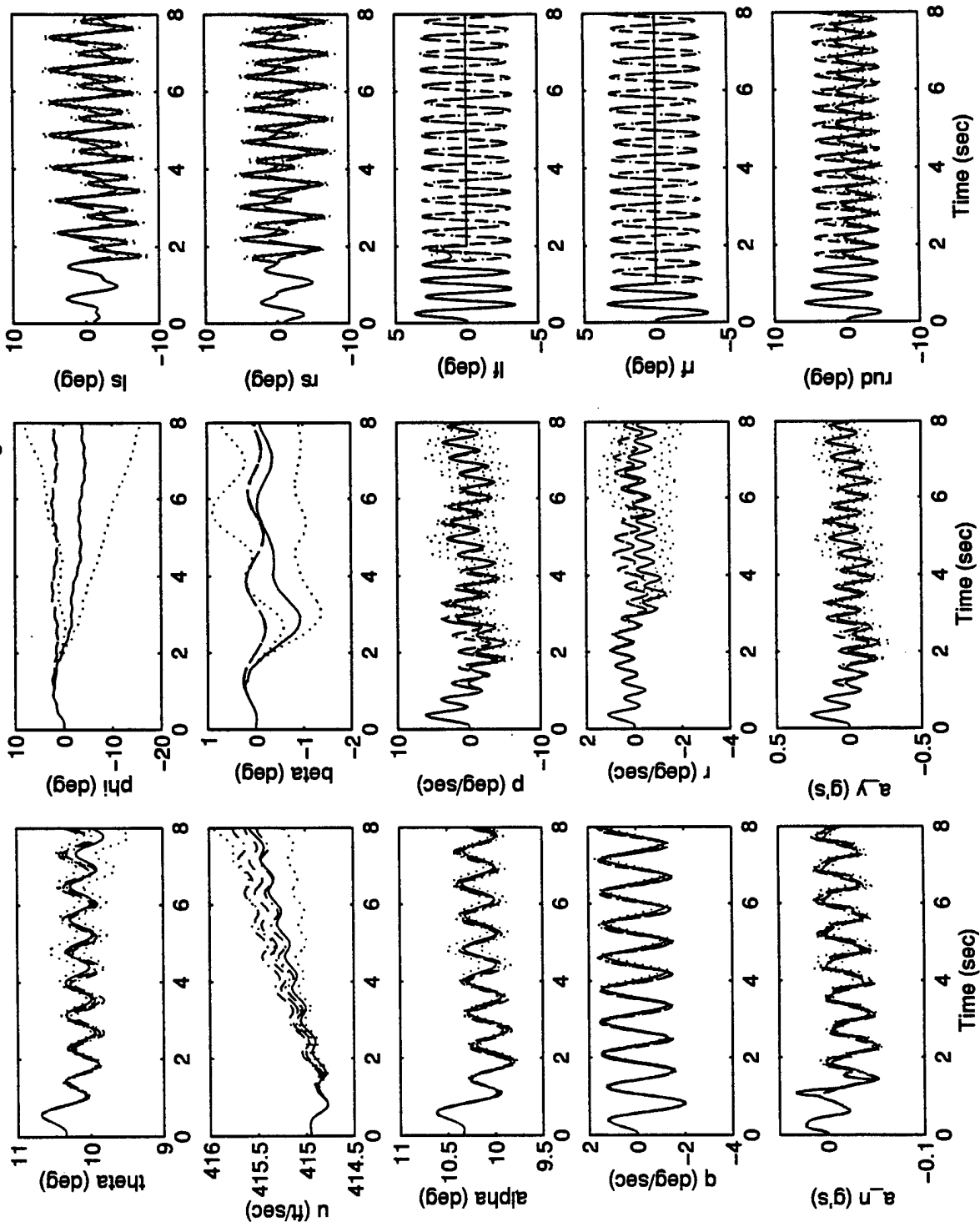dual–failure fail02.00 with reconfiguration
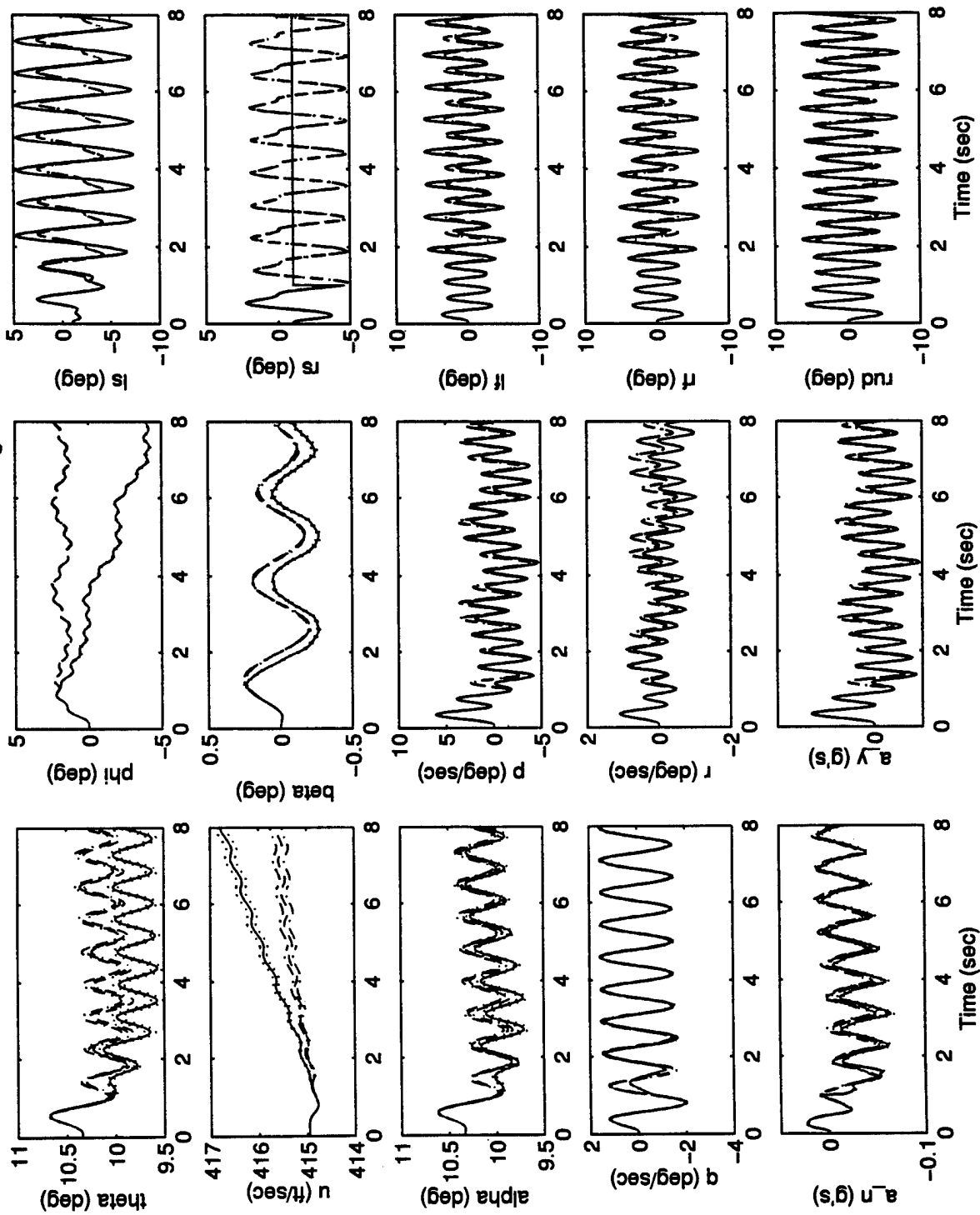
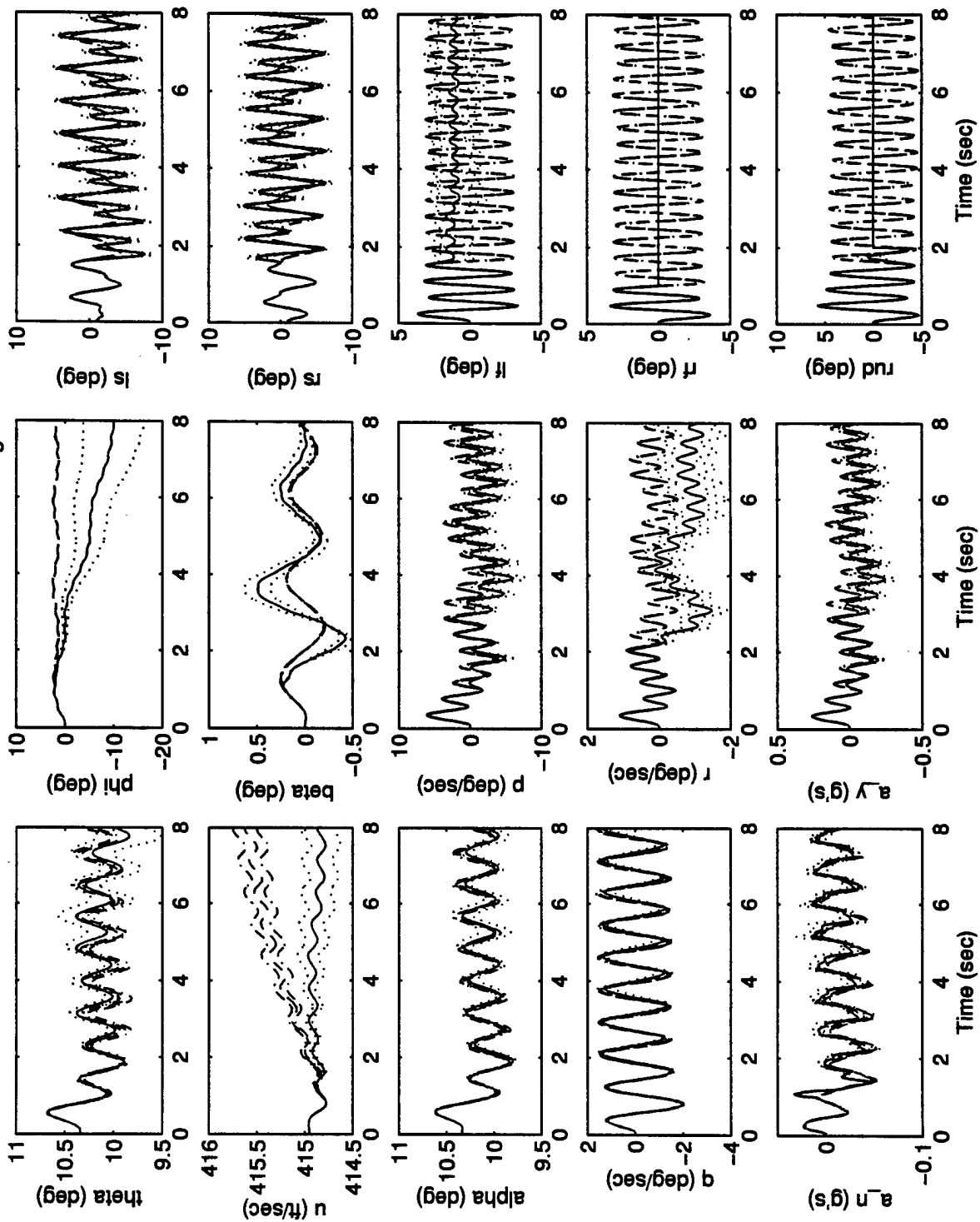dual–failure fail02.01 with reconfiguration
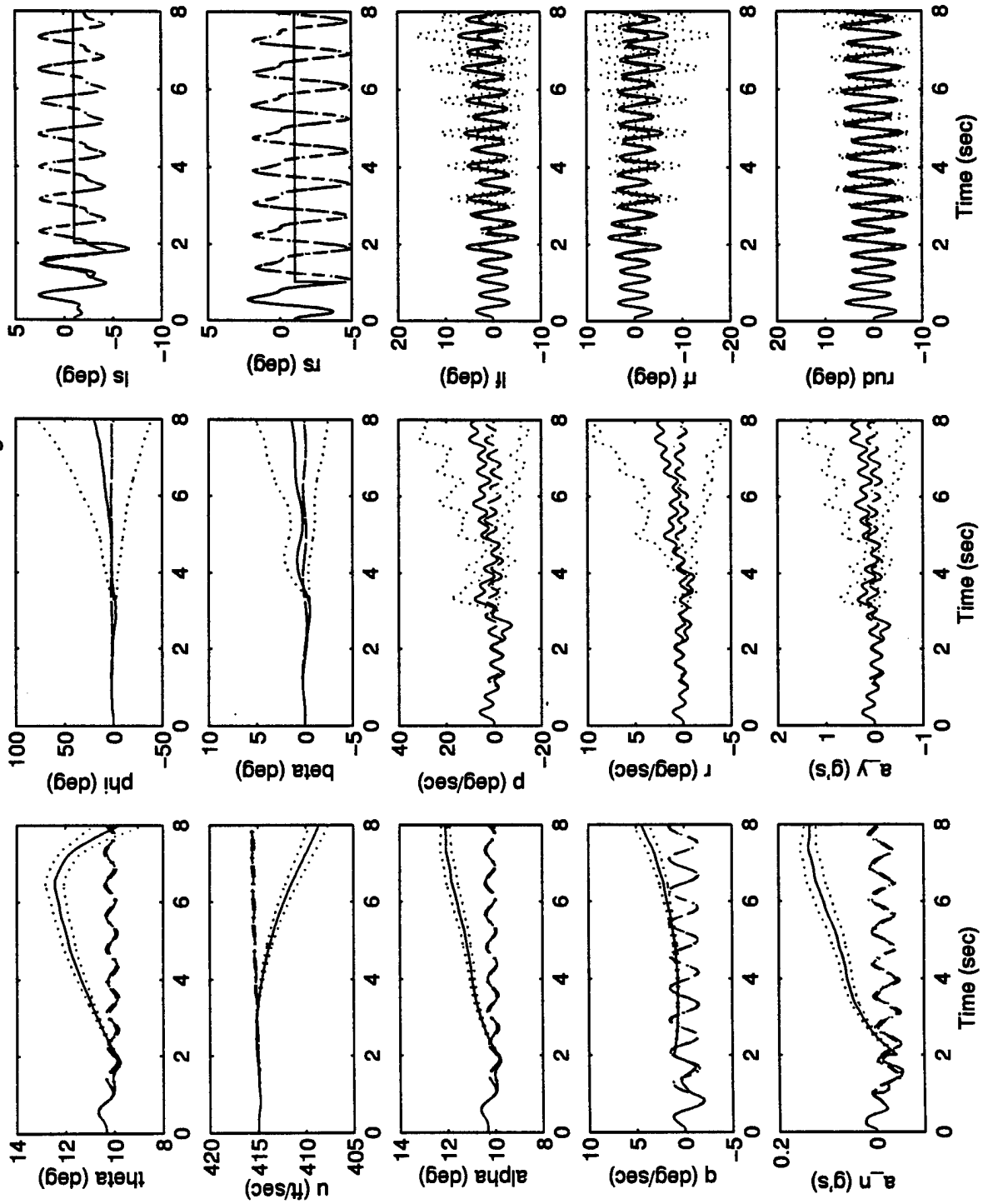
dual–failure fail02.03 with reconfiguration
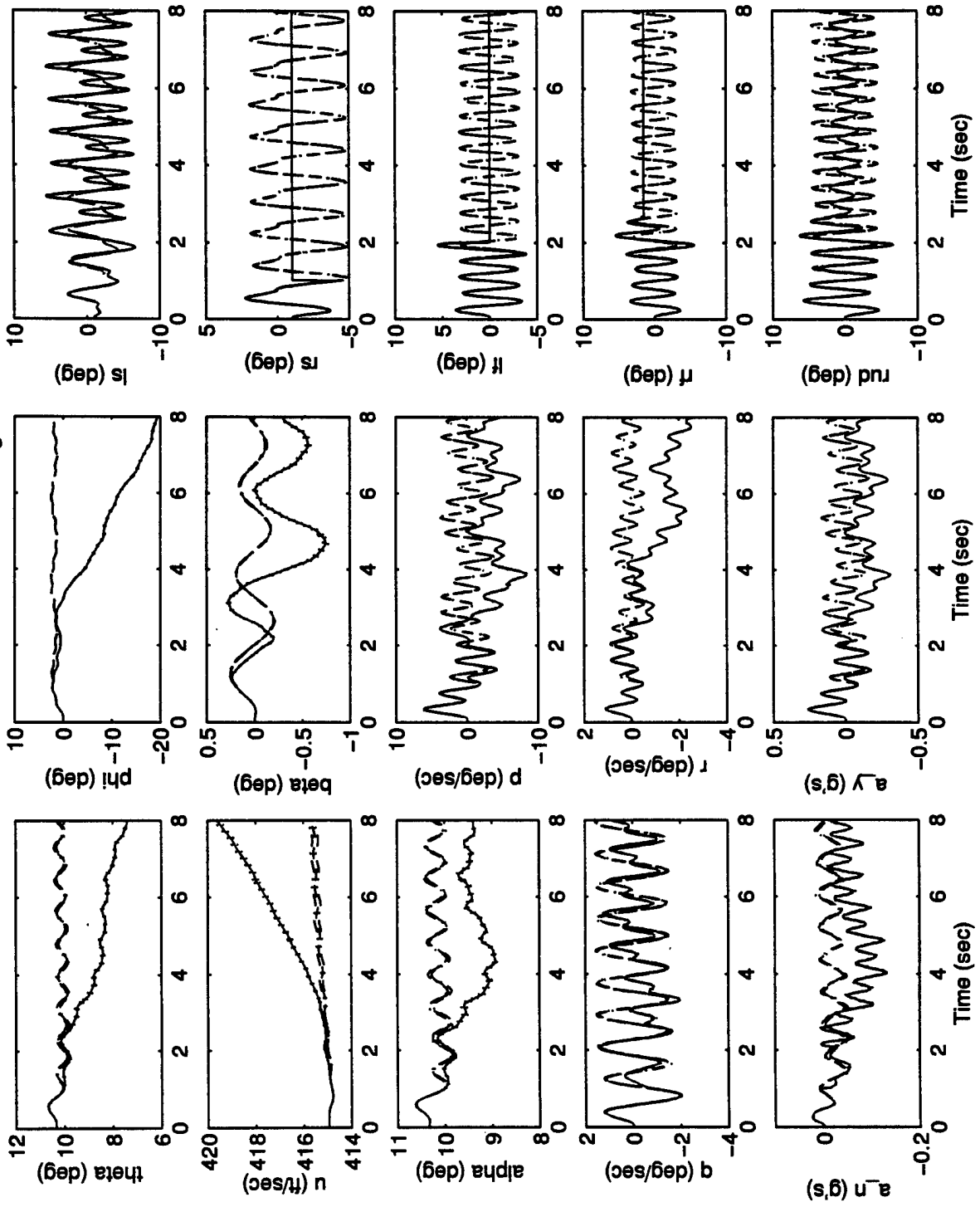
dual-failure fail02.04 with reconfiguration
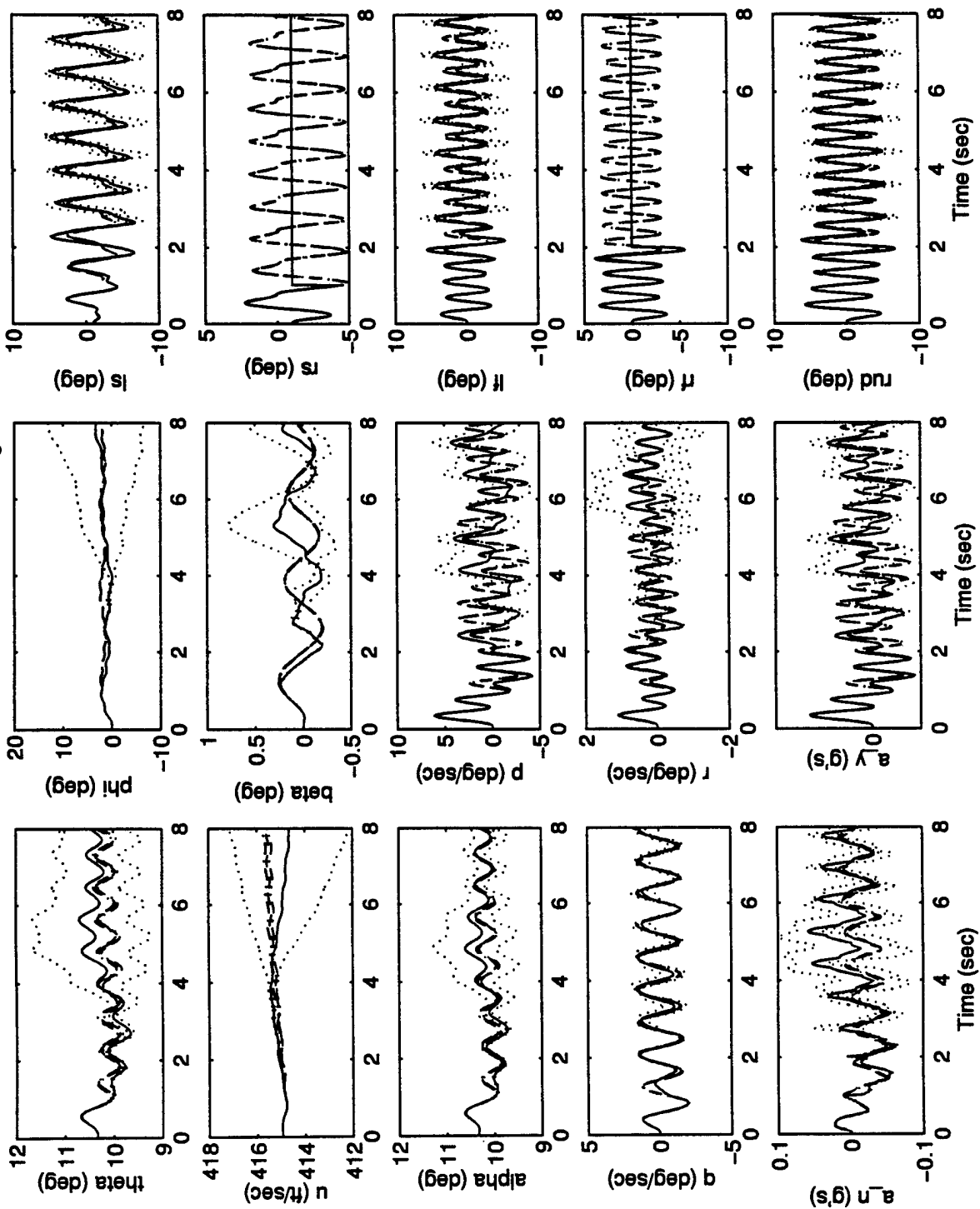
dual-failure fail02.05 with reconfiguration
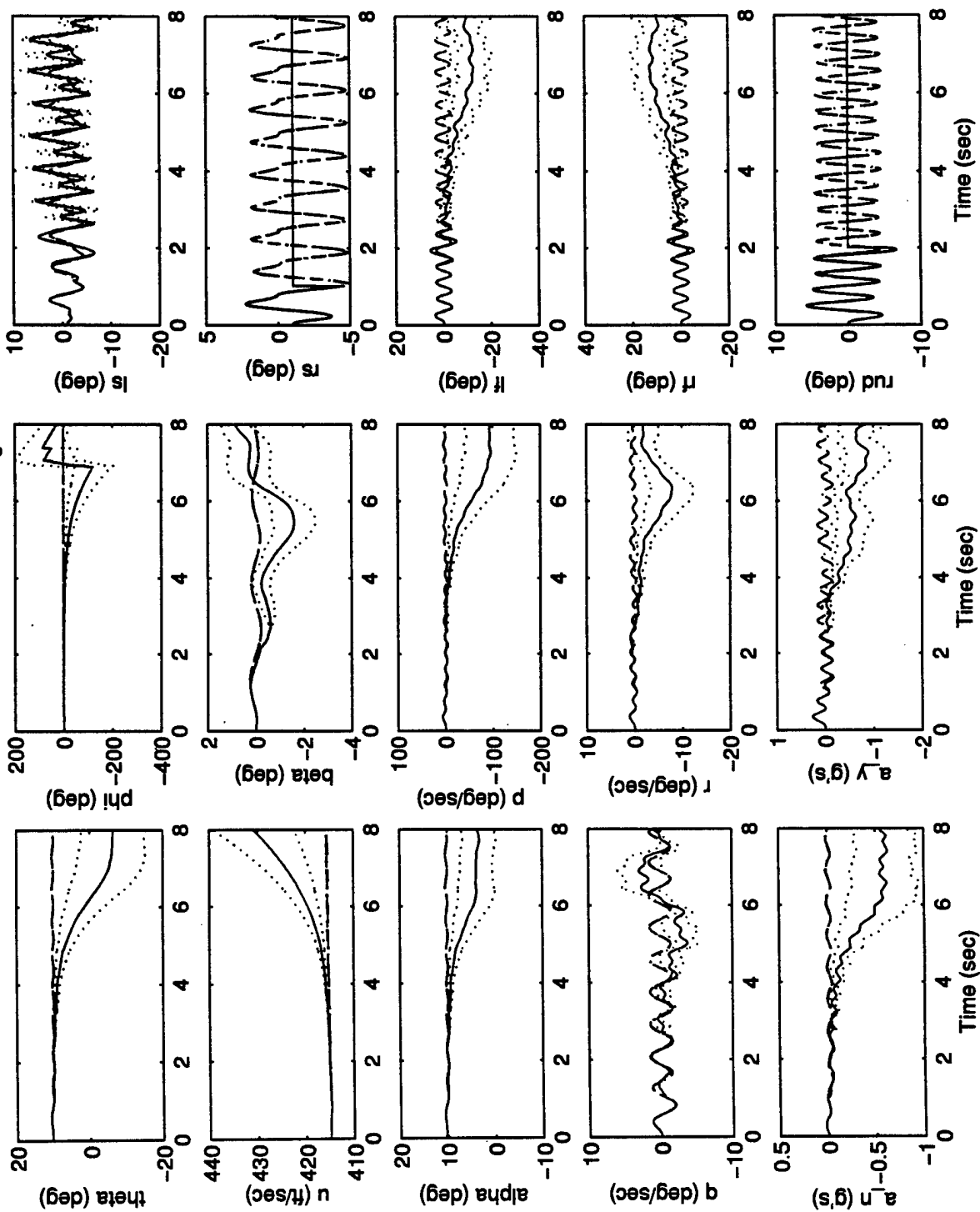
dual–failure fail002.006 with reconfiguration
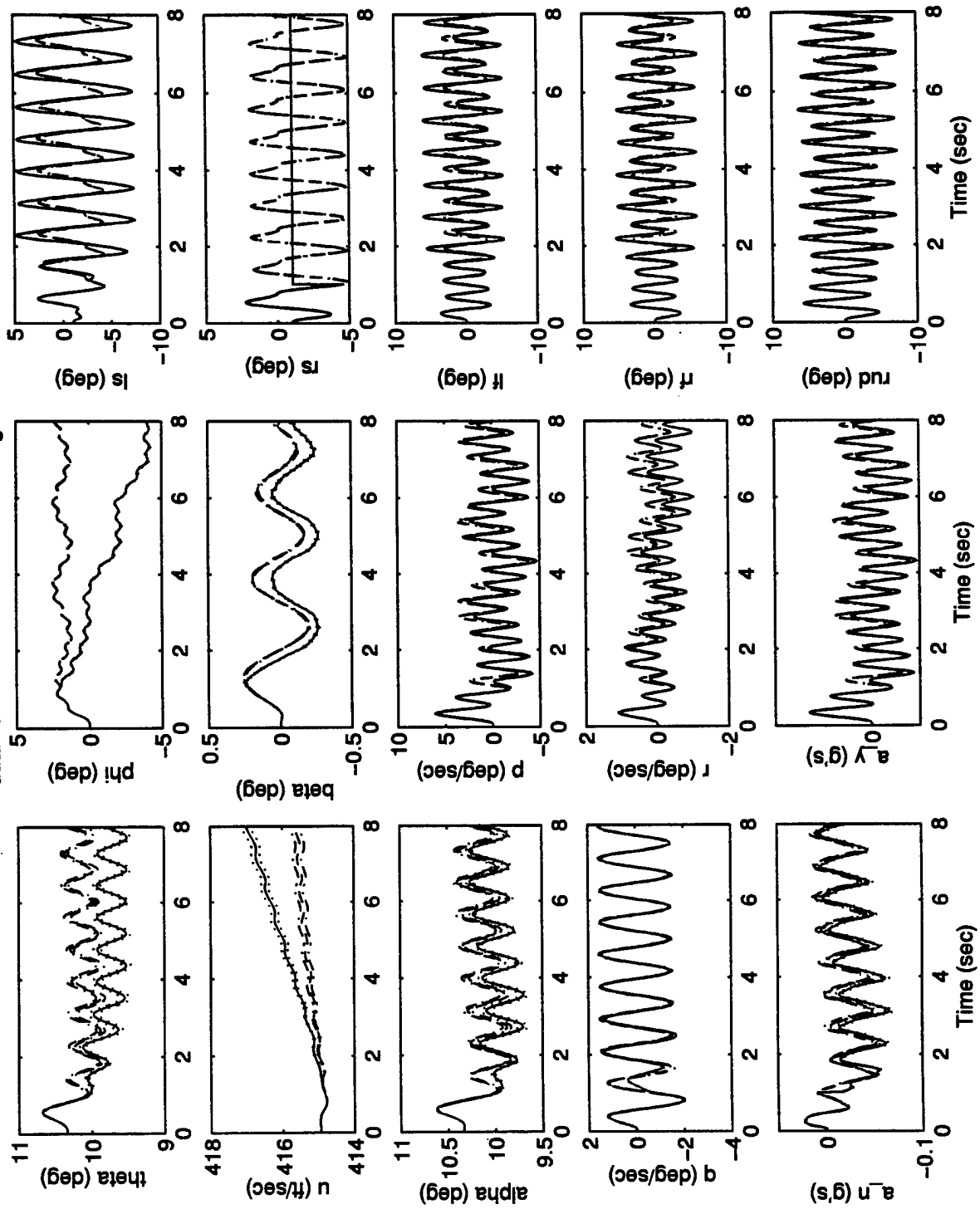
dual-failure fail002.007 with reconfiguration

dual-failure fail002.008 with reconfiguration

dual–failure fail002.009 with reconfiguration

dual-failure fail002.0010 with reconfiguration

dual-failure fail002.0011 with reconfiguration

dual-failure fail03.00 with reconfiguration

dual-failure fail03.01 with reconfiguration

dual-failure fail03.02 with reconfiguration

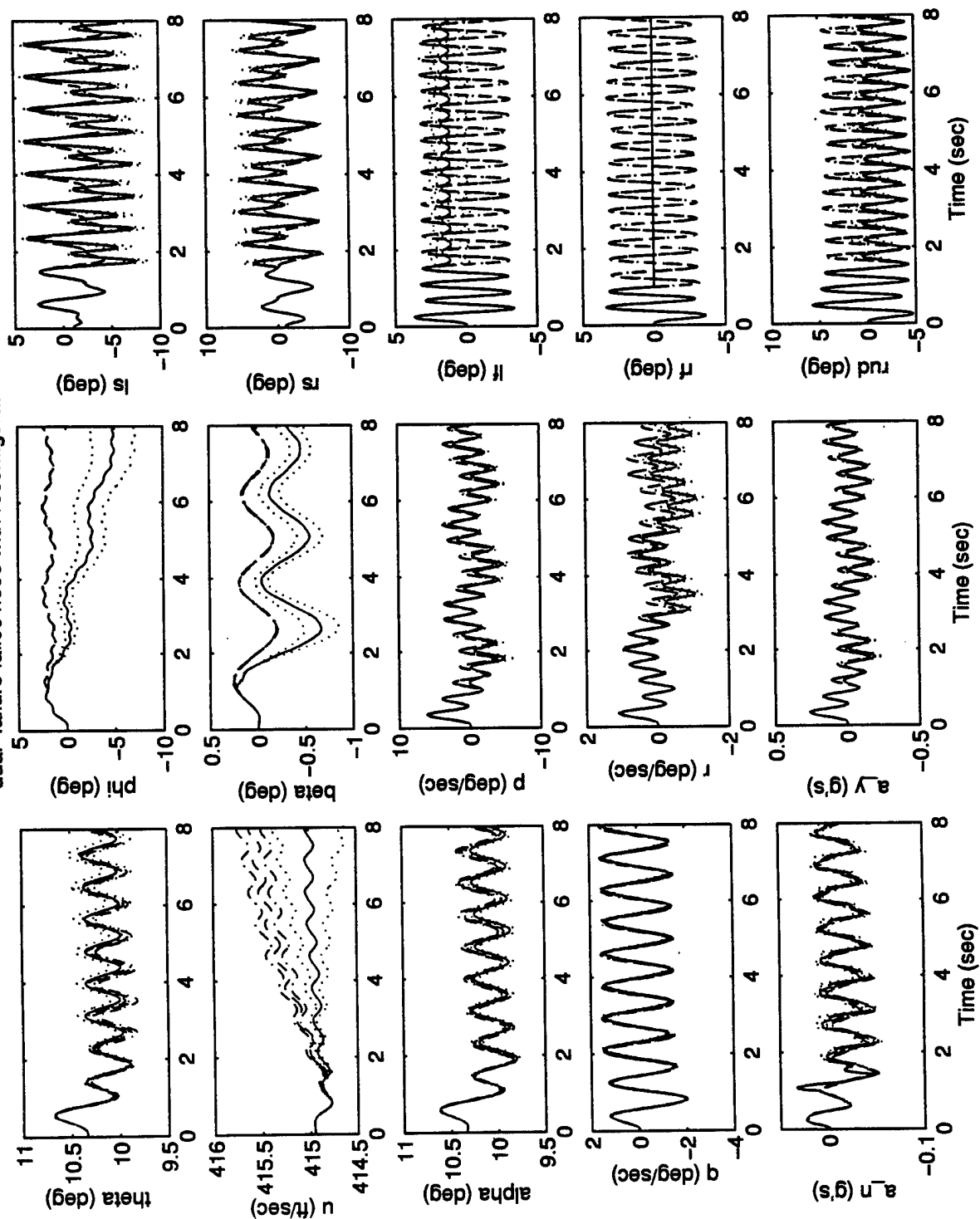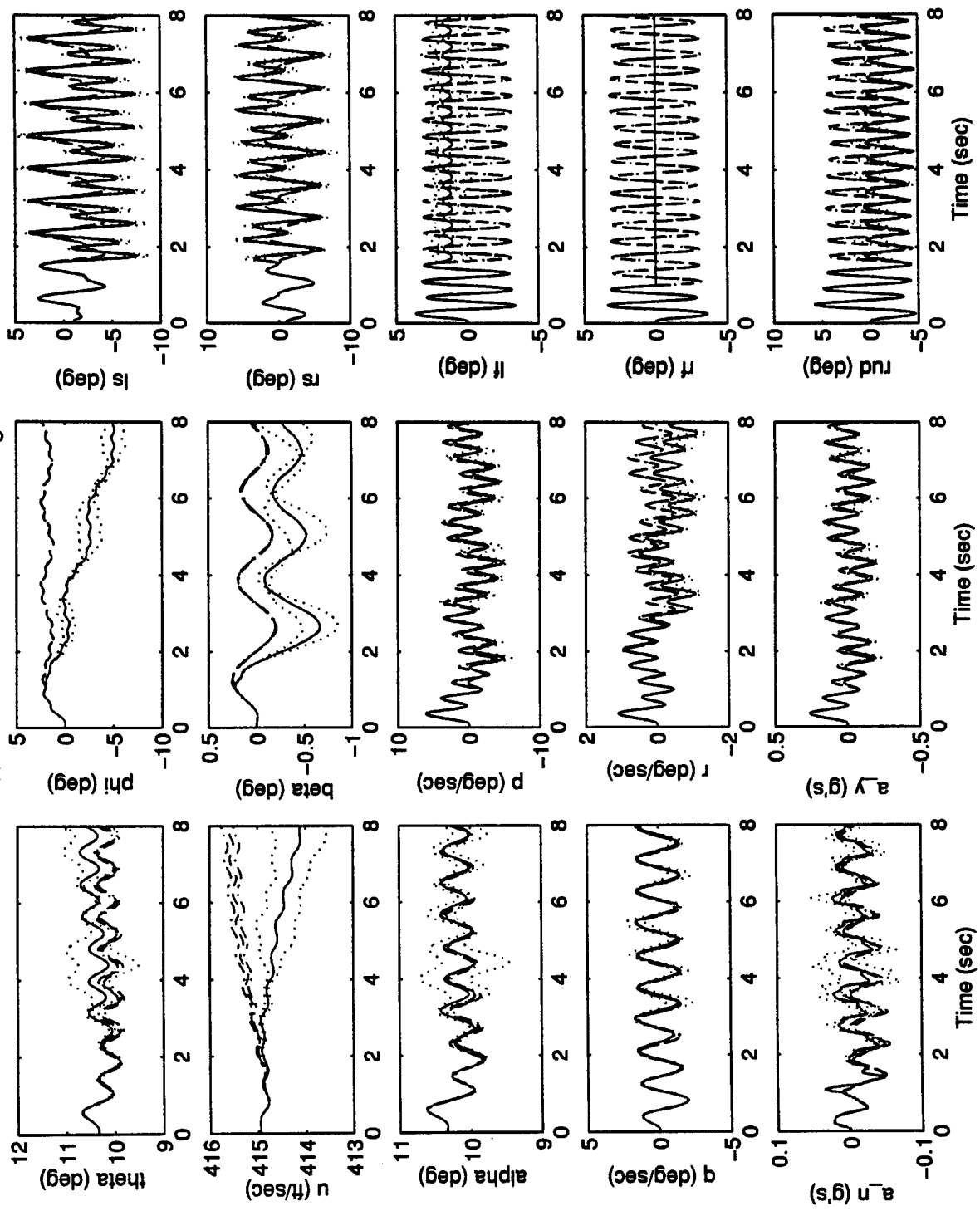dual-failure fail03.04 with reconfiguration

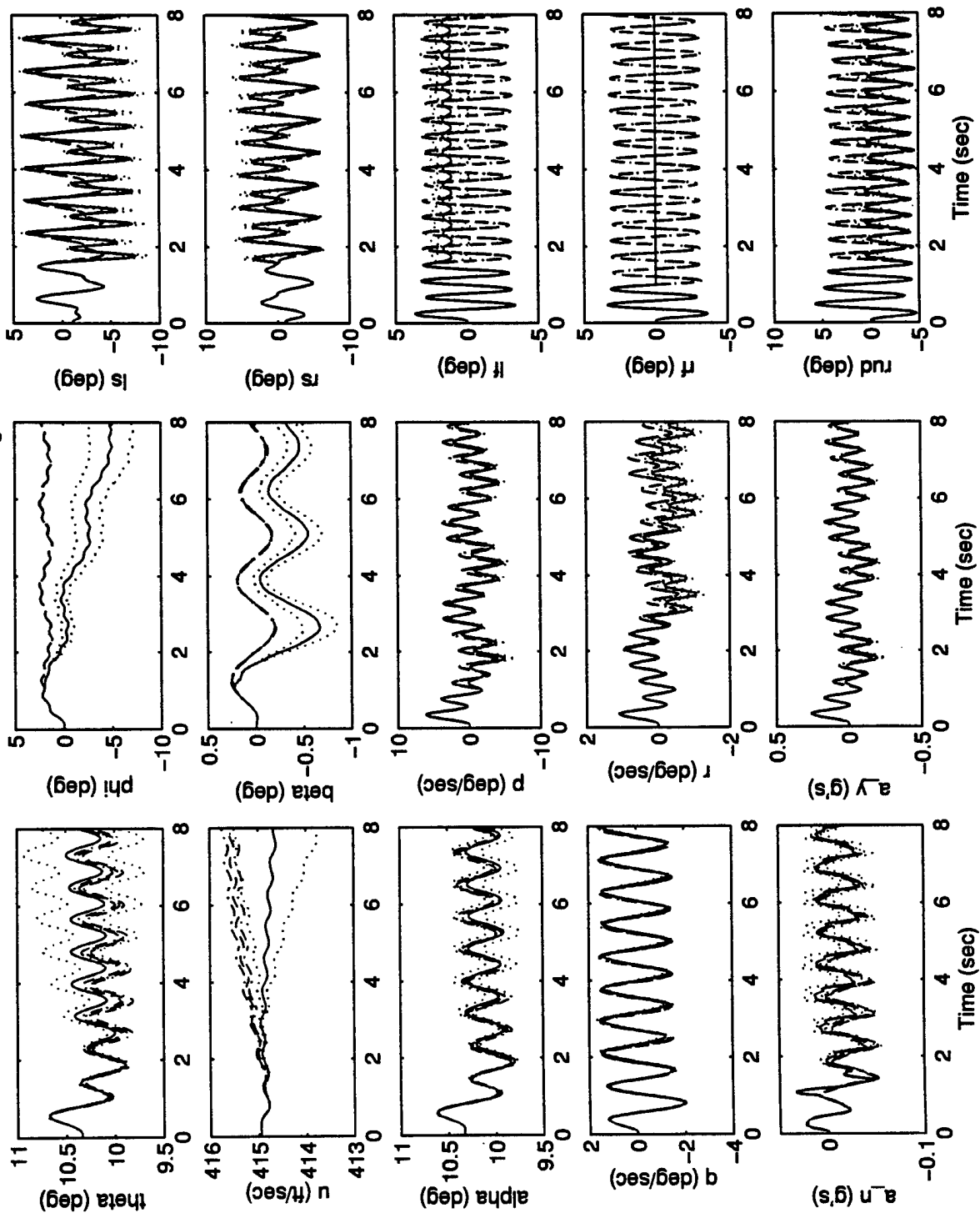dual-failure fail03.05 with reconfiguration

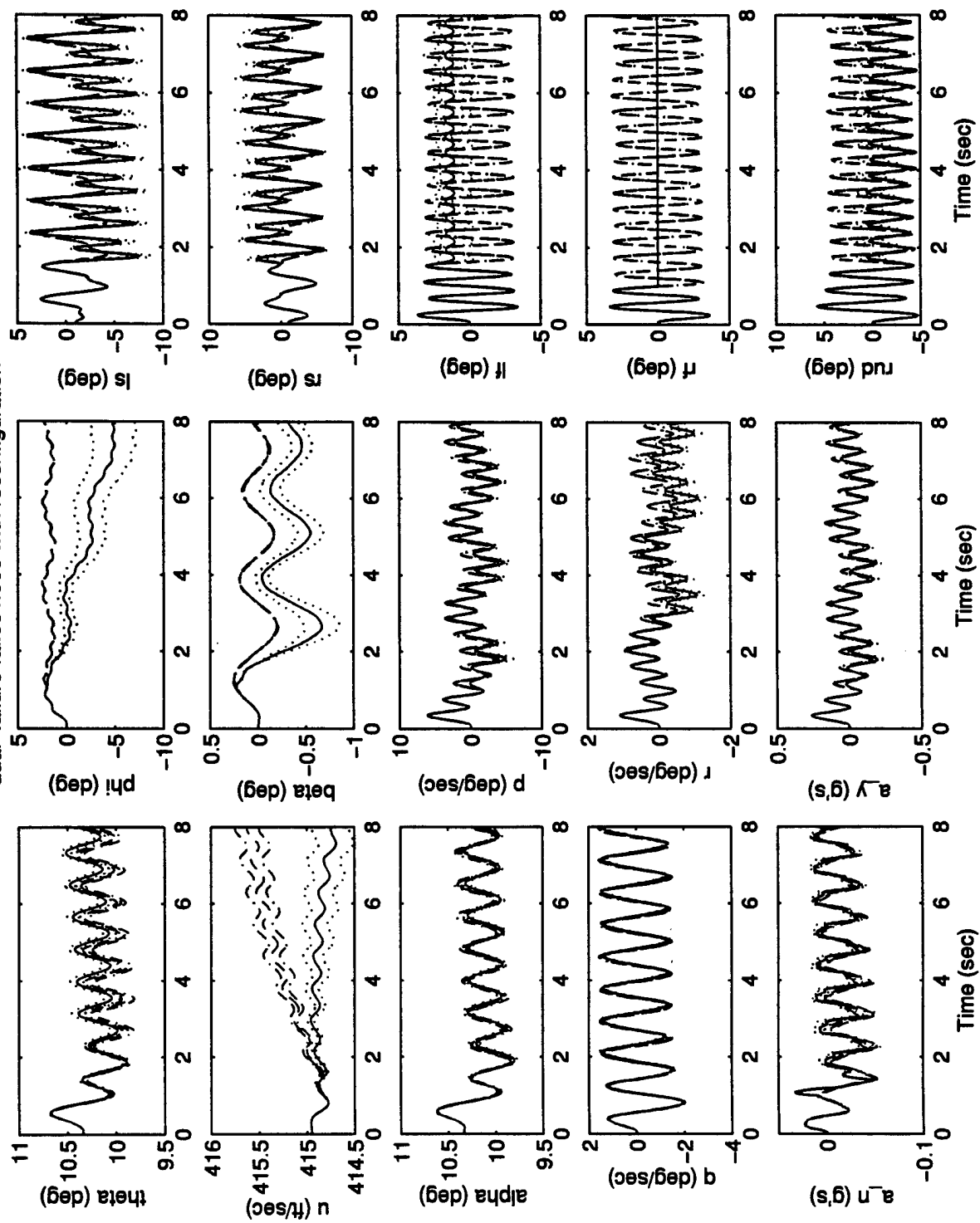dual-failure fail003.006 with reconfiguration

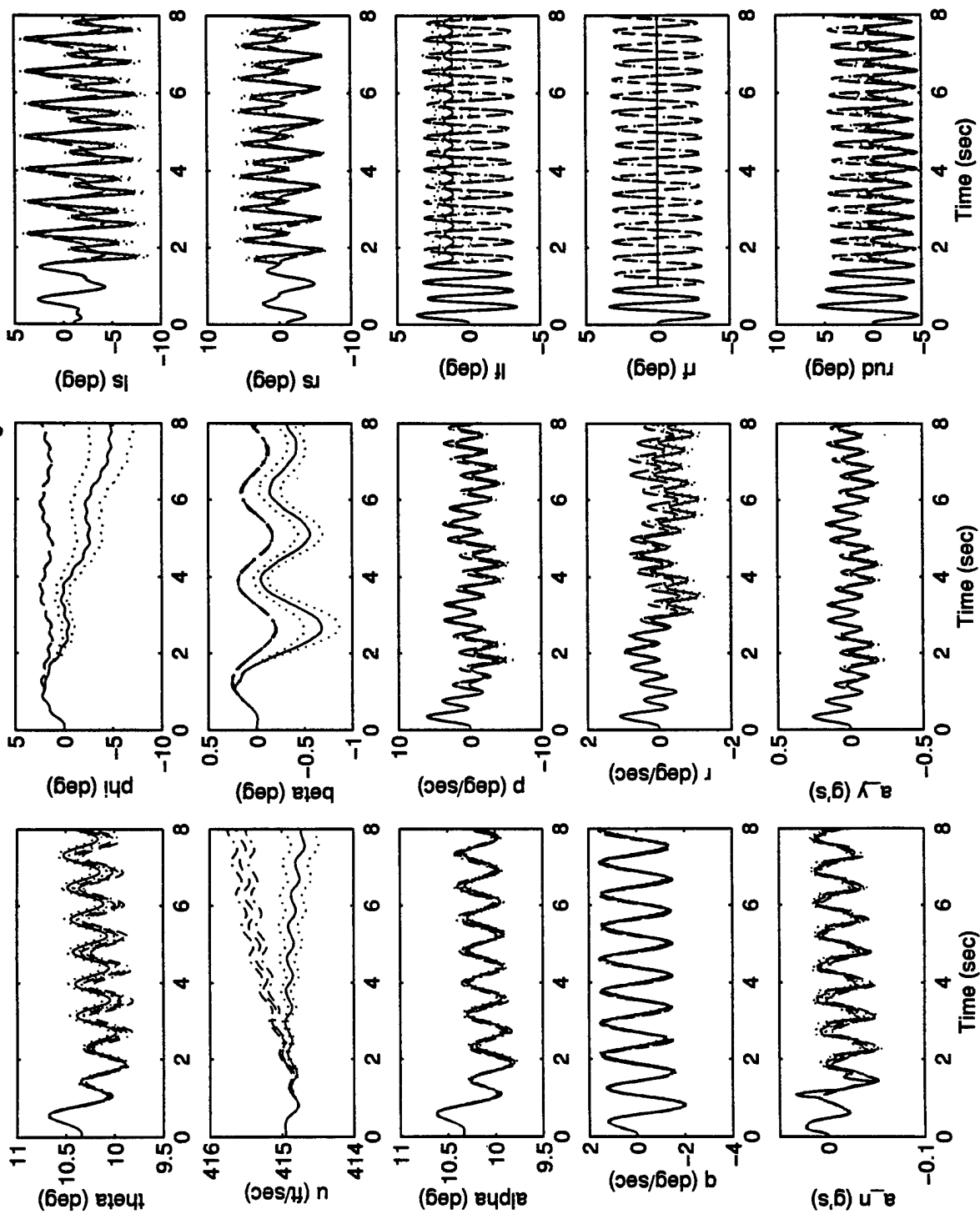dual-failure fail003.007 with reconfiguration
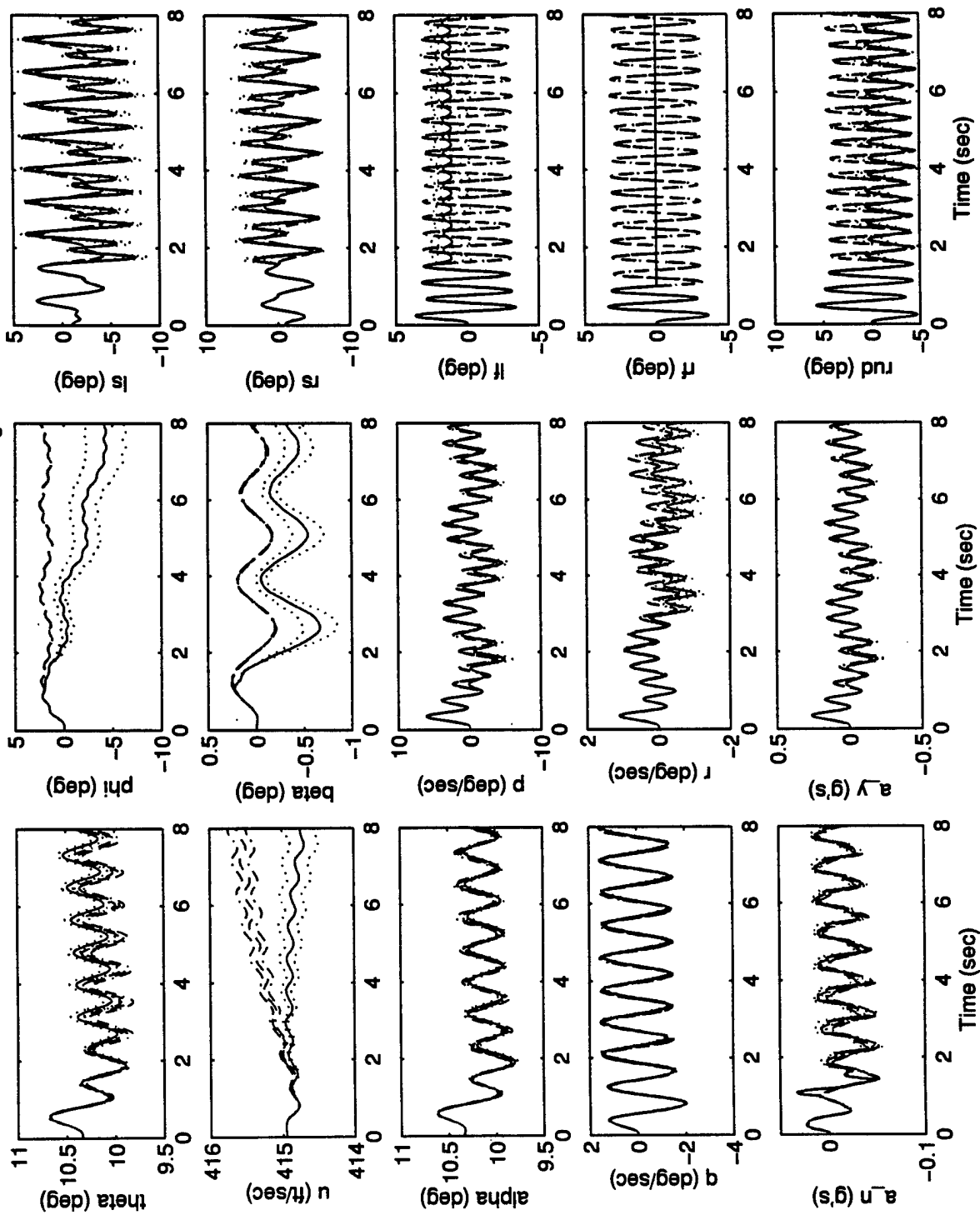
dual–failure fail003.008 with reconfiguration

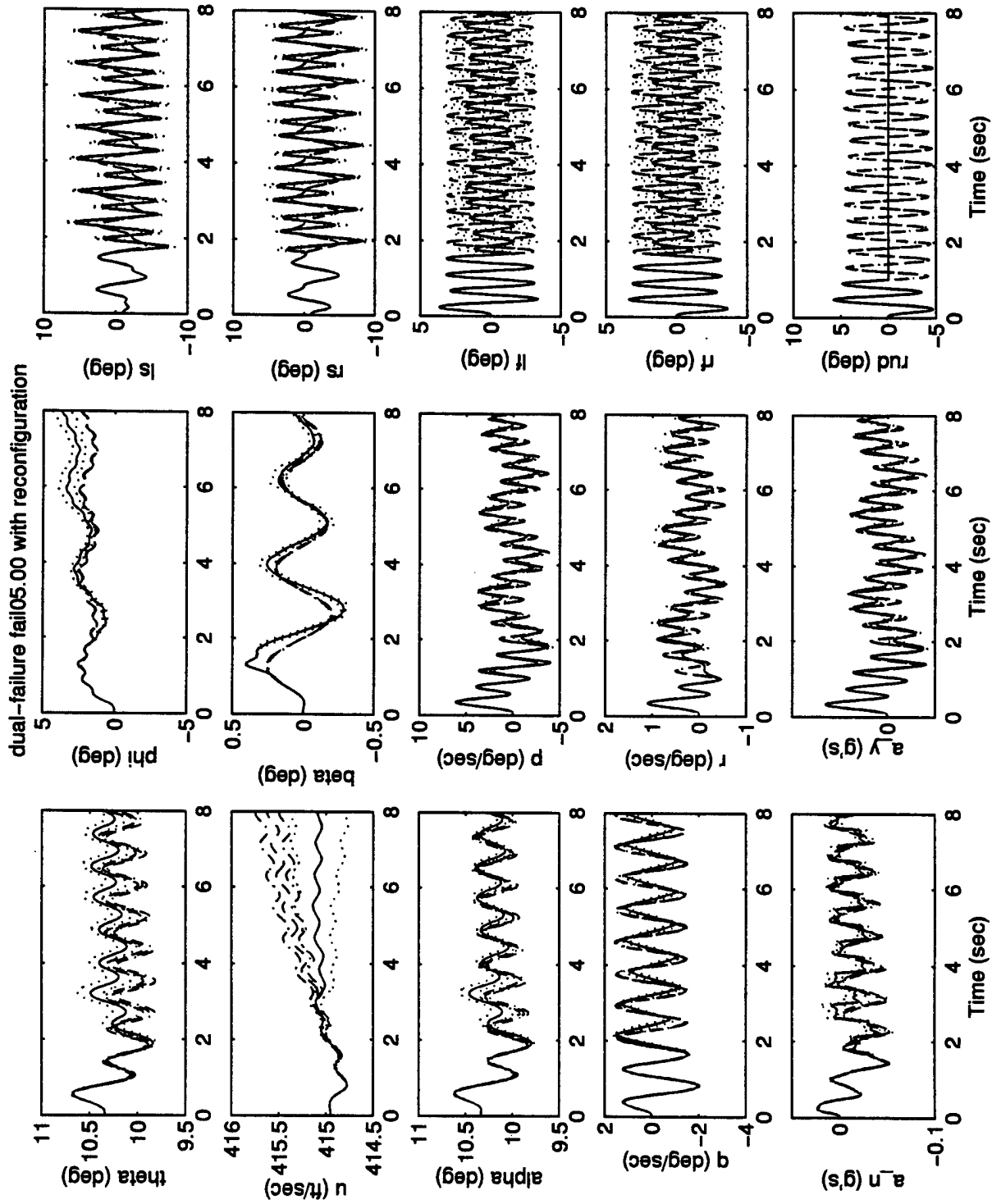dual-failure fail003.009 with reconfiguration

dual–failure fail003.0010 with reconfiguration

dual-failure fail003.0011 with reconfiguration

dual-failure fail04.00 with reconfiguration

dual-failure fail04.01 with reconfiguration

dual-failure fail04.02 with reconfiguration

dual-failure fail04.03 with reconfiguration
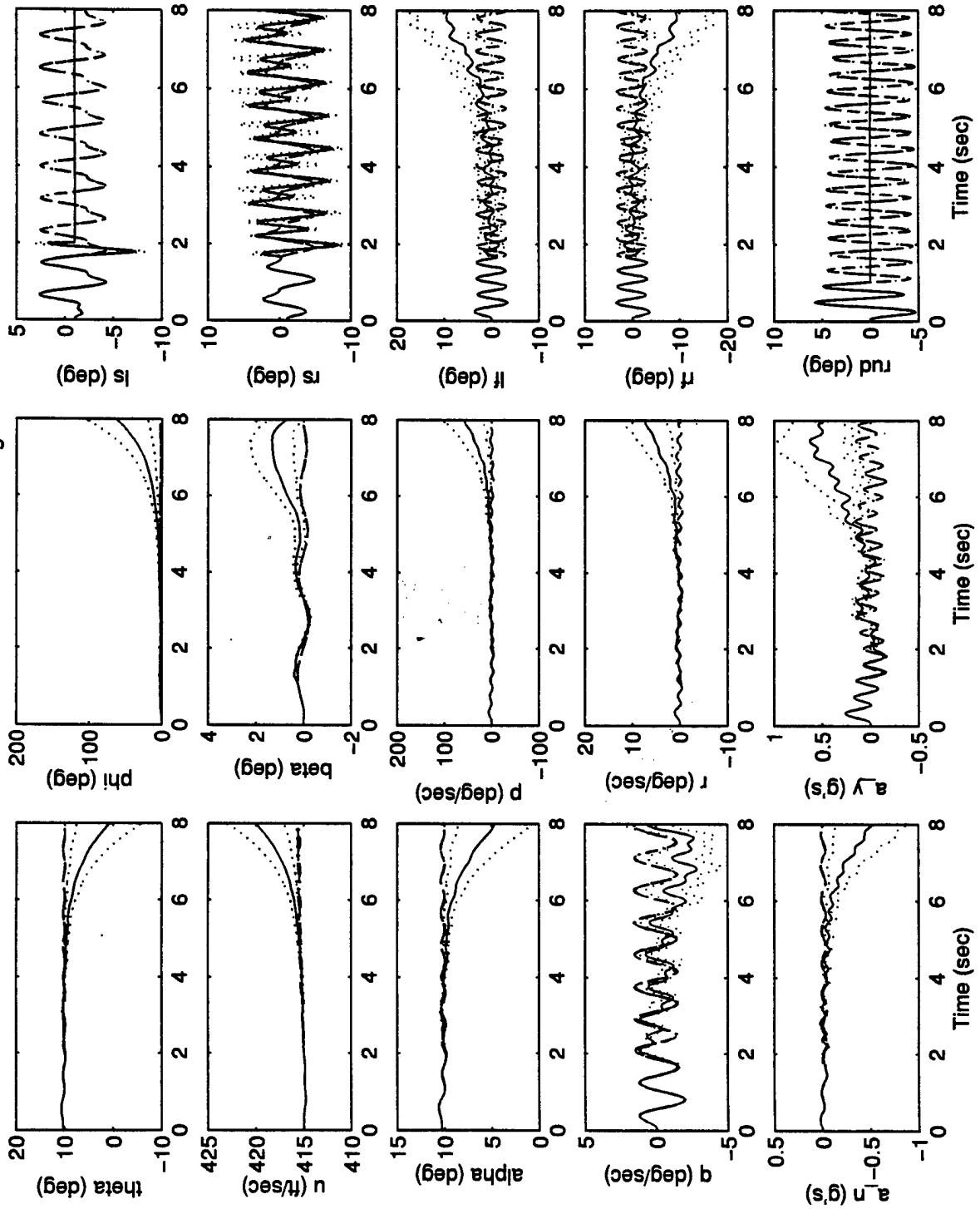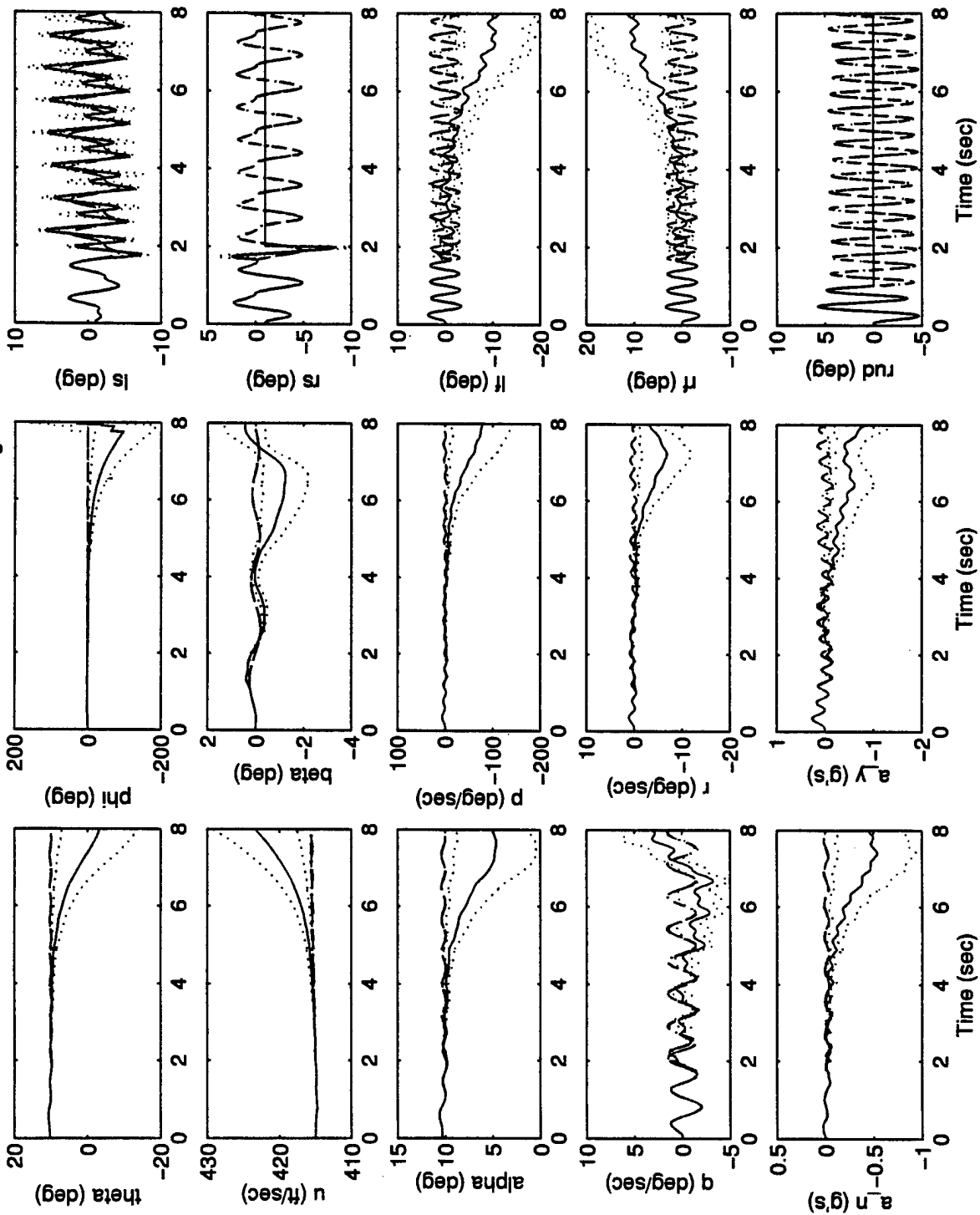
dual-failure fail04.05 with reconfiguration

dual-failure fail004.006 with reconfiguration

dual-failure fail004.007 with reconfiguration

dual-failure fail004.008 with reconfiguration

dual-failure fail004.009 with reconfiguration

dual–failure fail004.0010 with reconfiguration
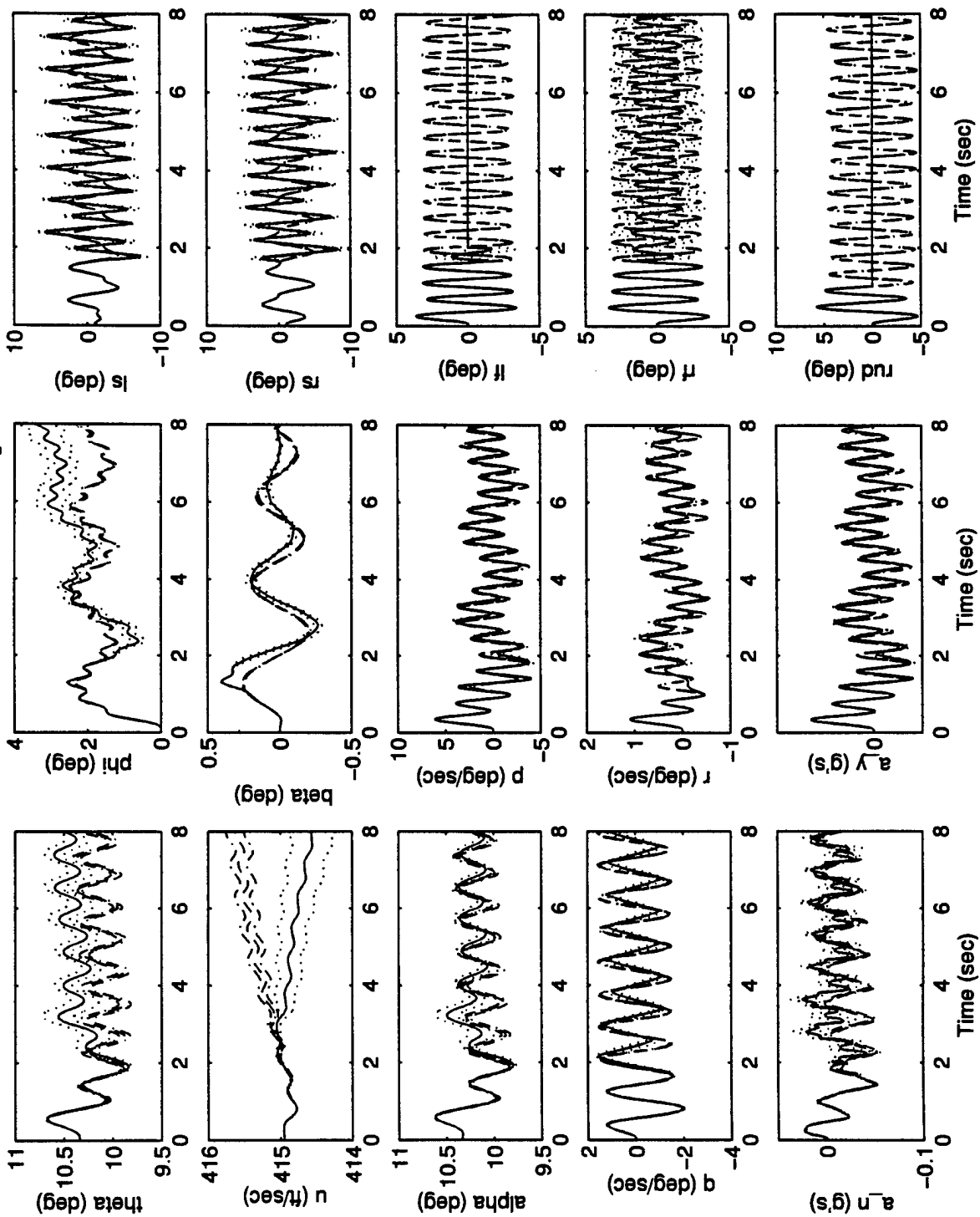
dual-failure fail004.0011 with reconfiguration
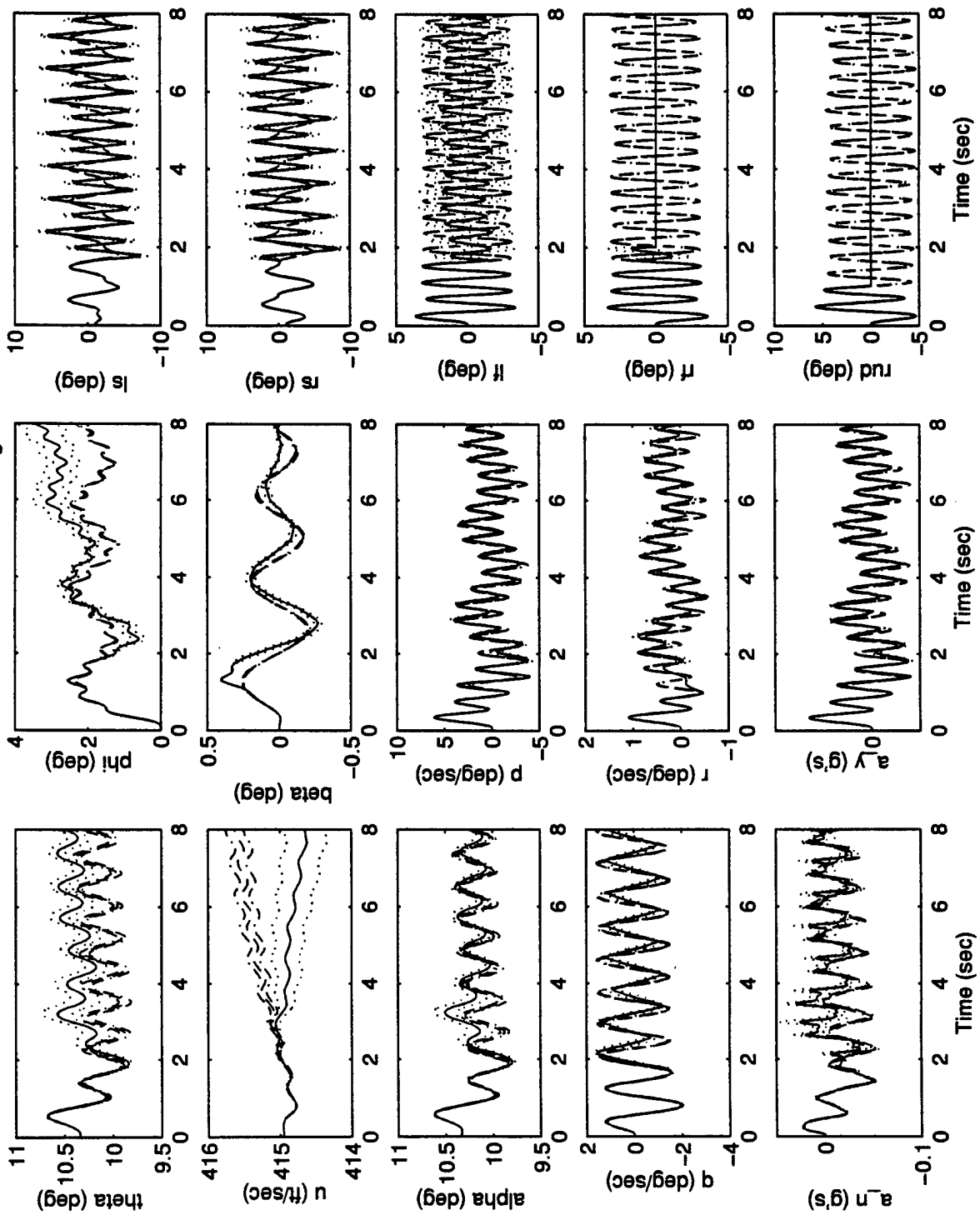
dual-failure fail05.00 with reconfiguration
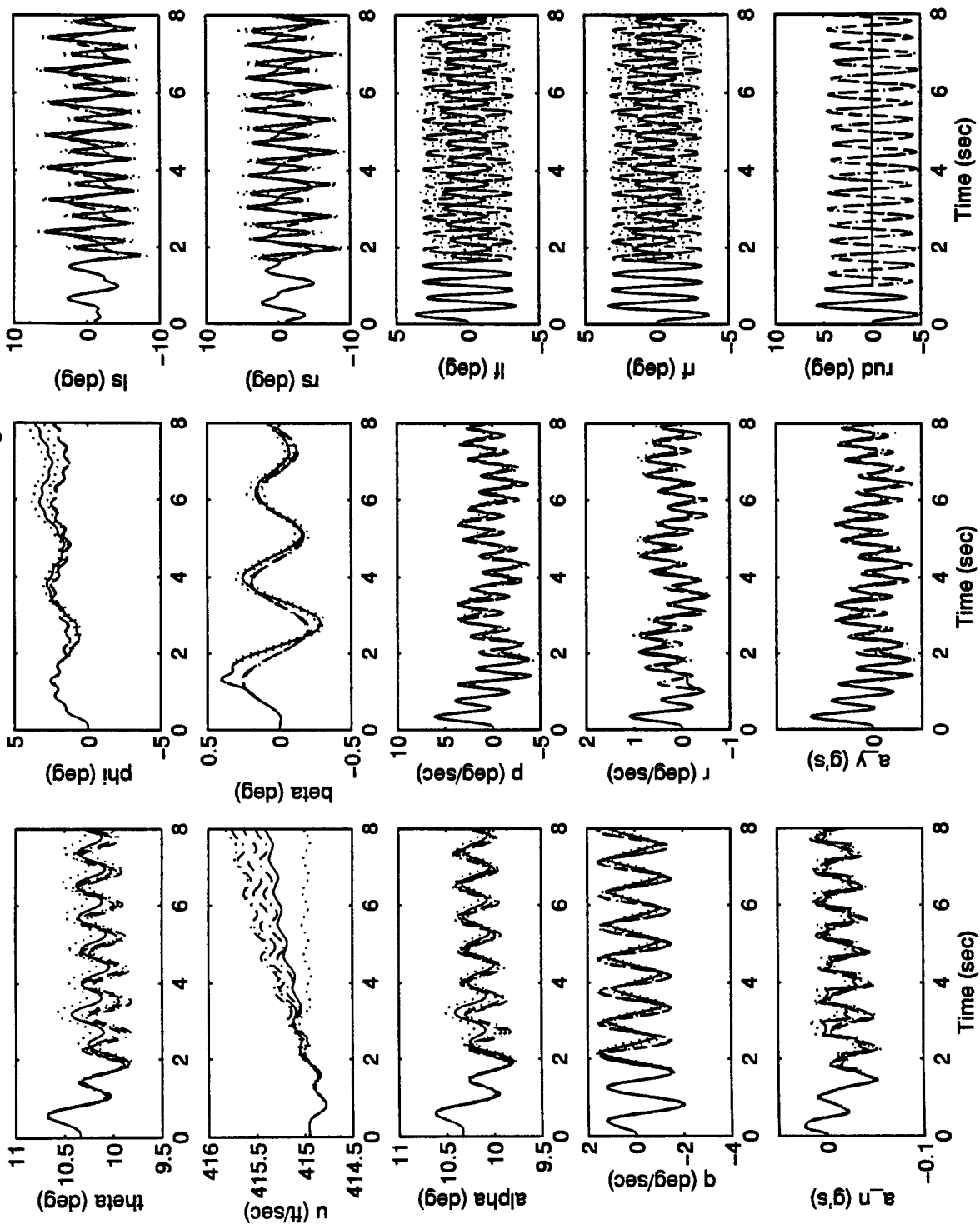
dual-failure fail05.01 with reconfiguration

theta (deg)
u (ft/sec)
alpha (deg)
q (deg/sec)
a_n (g's)
Time (sec)

phi (deg)
beta (deg)
p (deg/sec)
r (deg/sec)
a_y (g's)
Time (sec)

ls (deg)
rs (deg)
lf (deg)
rf (deg)
rud (deg)
Time (sec)

dual-failure fail05.02 with reconfiguration

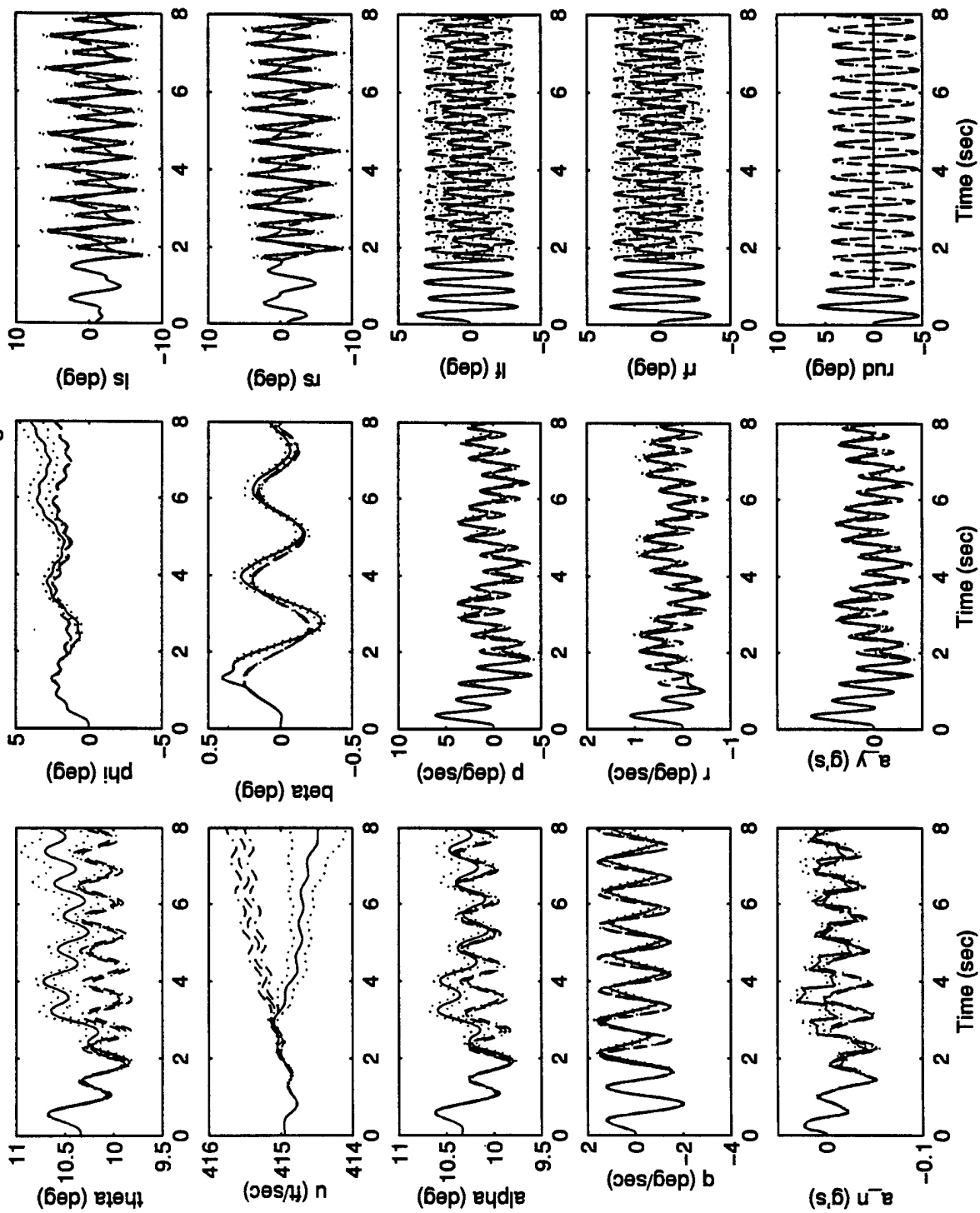dual-failure fail05.03 with reconfiguration
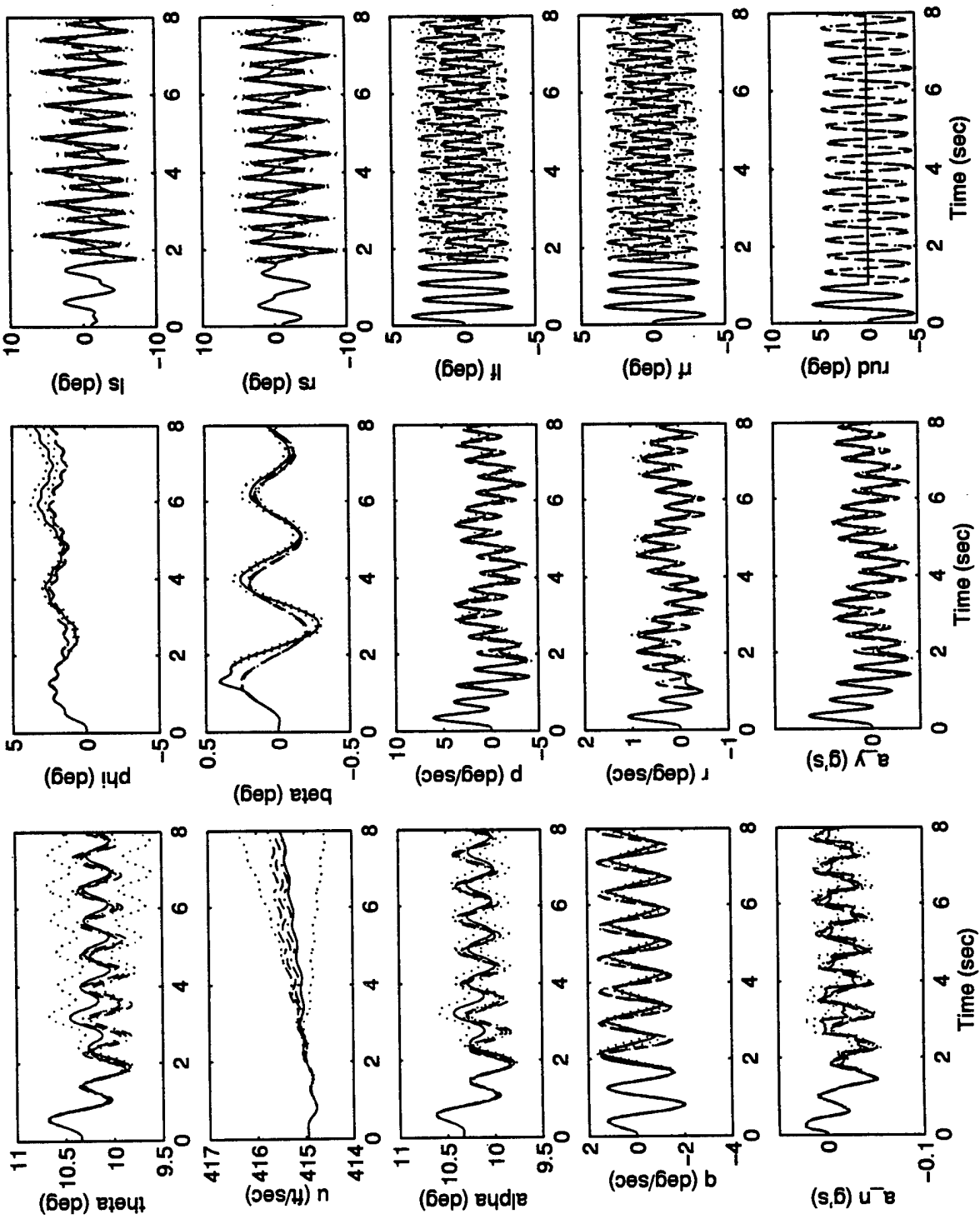
dual-failure fail05.04 with reconfiguration

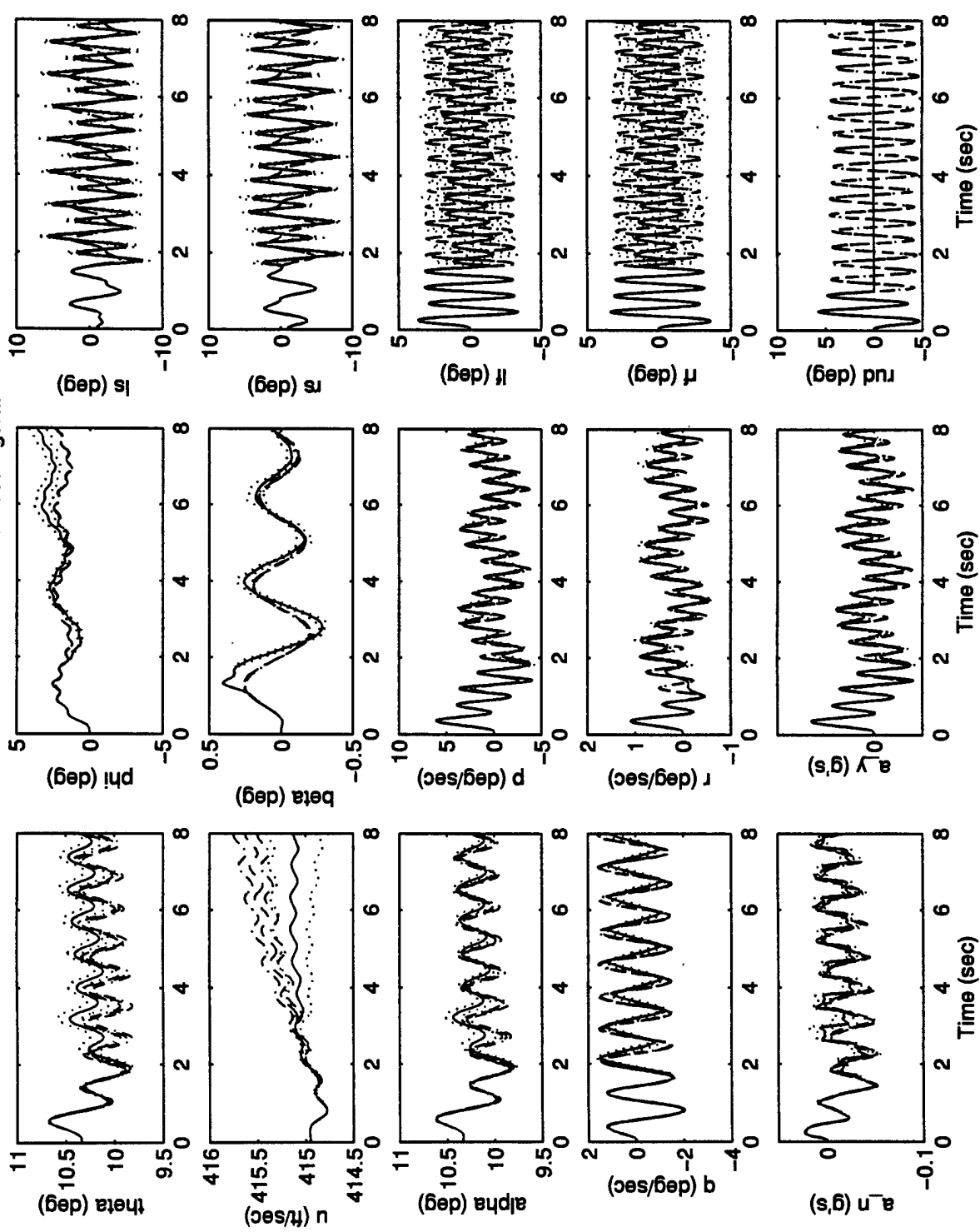dual-failure fail005.006 with reconfiguration

dual-failure fail005.007 with reconfiguration

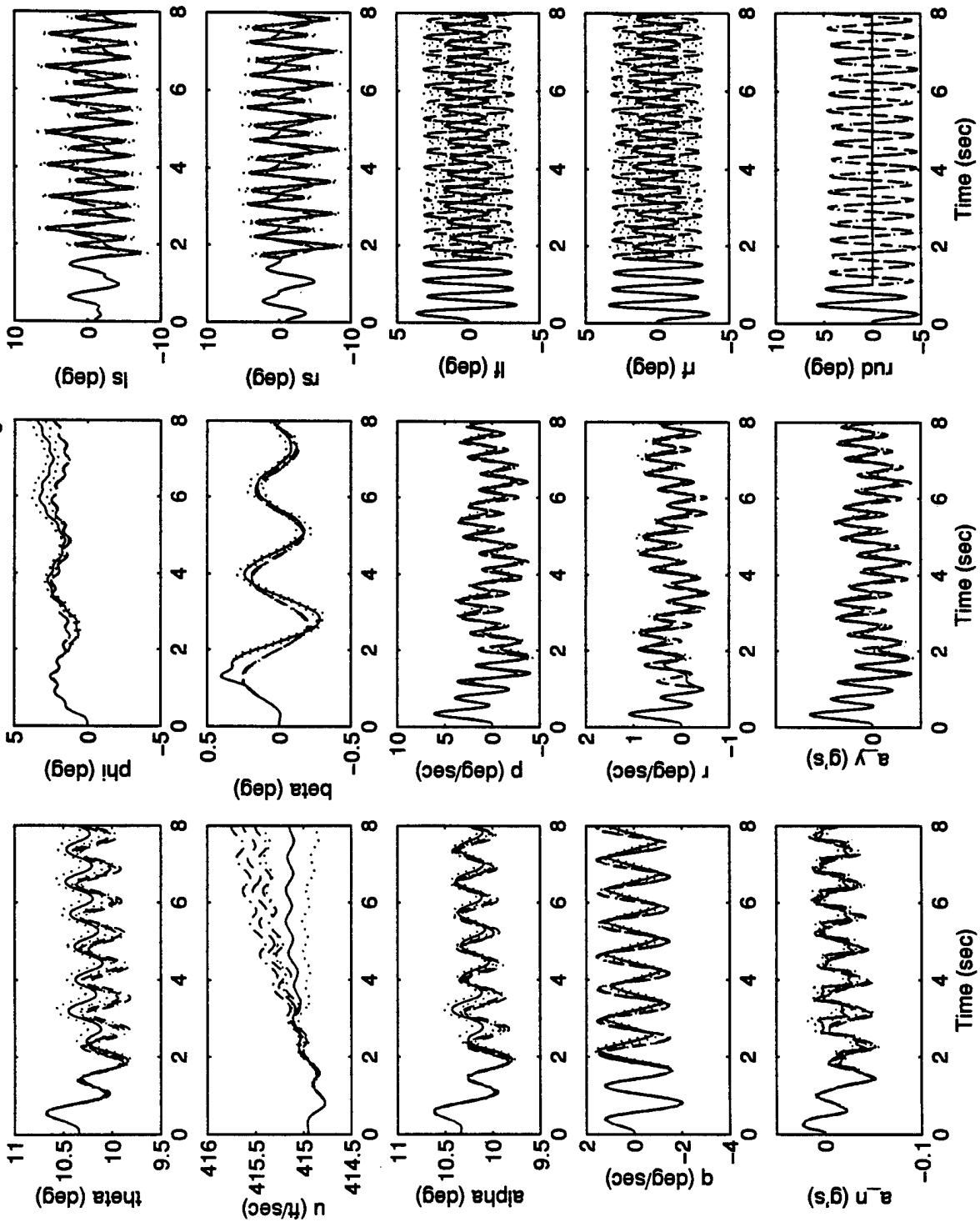dual-failure fail005.008 with reconfiguration

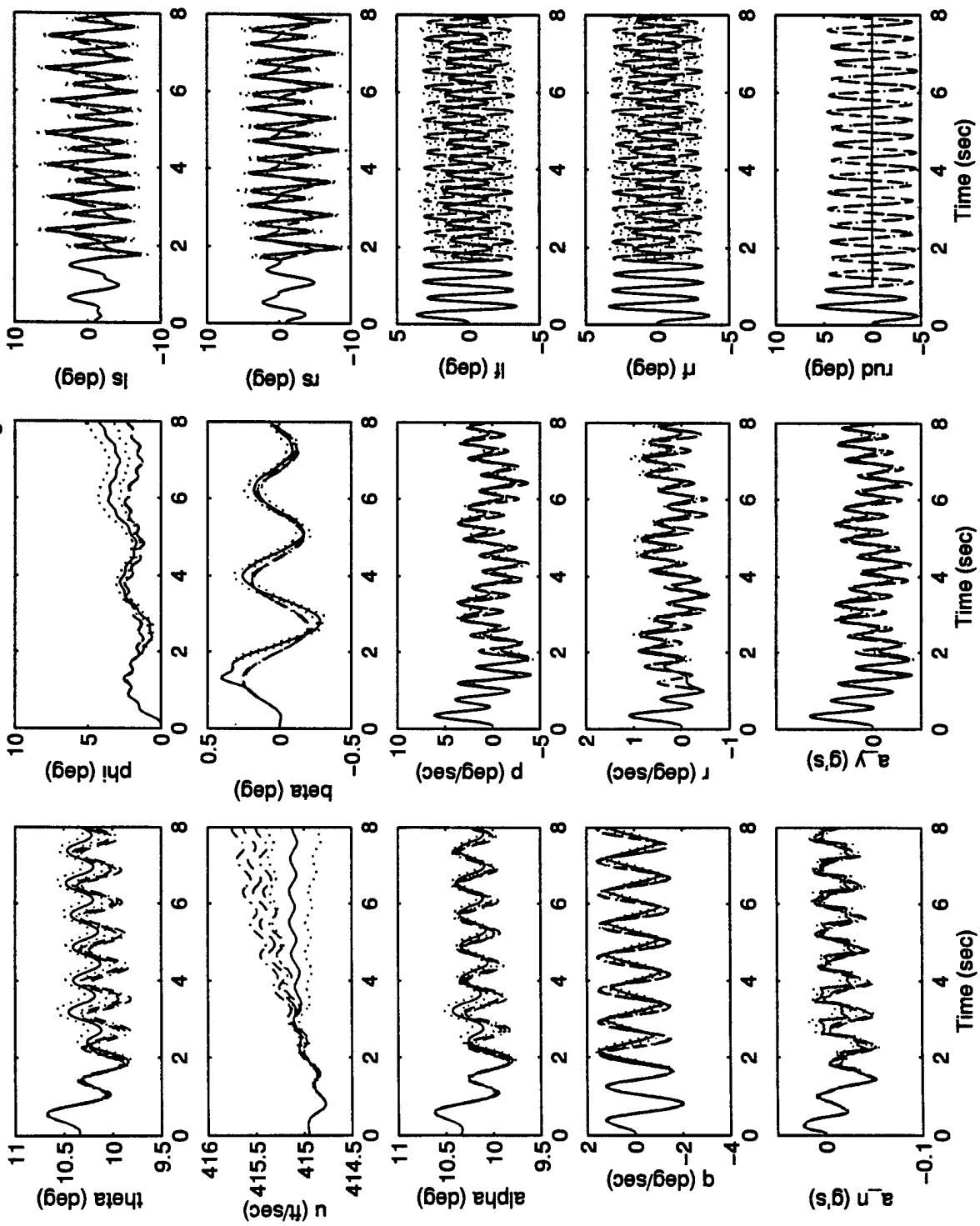dual-failure fail005.009 with reconfiguration

dual-failure fail005.0010 with reconfiguration

dual-failure fail005.0011 with reconfiguration

Appendix H.2: State Plots For Dual, 75% Actuator (ε = .25) and 75%-Actuator / Total -Sensor

Impairments, Control Redistribution 'ON', Dither 'ON', No Maneuvers

This appendix contains the state plots for "75% actuator / 75% actuator" and "75% actuator / total sensor" dual impairment scenarios, *with* Control Reconfiguration (Redistribution) and with control dithering (Section 4.12.3 and Appendix D.2). The first impairment is inserted at 1 second, followed by the second impairment at 2 seconds, and in all cases, there is no aircraft maneuvering. Table H.2 on the following page lists the impairment cases, by case number, which are to be found in this appendix. The leftmost column of Table H.2 represents the first impairment occurring at 1 second, while the top row represents the second impairment occurring at 2 seconds. The table entries list the failure codes found in the plot titles for the failure case represented by the table row and column. **Bold** entries correspond to cases of no second impairment. As an example, the entry for a left stabilator (LS) impairment at 1 second, followed by a right flaperon (RF) impairment at 2 seconds is found in entry '(LS, RF)' in the table, and the corresponding failure case is 'fail251.254'. The state plot will contain this code ('fail251.254') in the plot title. In fact, for this specific case, the plot title is: "dual-failure fail251.254 with reconfiguration". Each page of State Plots in this appendix contains three columns of five plots and corresponds to one impairment condition, or test point. The first column shows the aircraft longitudinal states and normal acceleration (a_n). Column two shows lateral-directional states and lateral acceleration (a_y). The third column, of most interest to us, displays actuator positions (not commands). Two actual time histories, the result of a 10-run Monte Carlo simulation of each impairment condition, are plotted on each of the 15 subplots. The first time history, a "dashed / dashed-dotted" trace, represents the "mean ± one standard deviation" of the *fully functional* aircraft response. The second time history is a "solid line / dotted" trace and represents the response of the *impaired* aircraft at the given impairment condition.

Special attention is directed to the following cases (see: Table H.2 on the next page): 'fail253.250', 'fail253.255', 'fail253.06', 'fail253.07', 'fail253.08', 'fail254.07', and 'fail254.08'. All plots appear to display the same "shark's tooth" appearance on the flaperon traces, which are often the telltale signs of actuator rate saturation (position saturation would display a "clipped" appearance). Due to a time shortage,

the exact causes for this were not found, but one possibility is that rate saturation may be occurring for cases when the actuator is wrongly detected by MMAE as a very large (but not total) impairment. If, for instance, MMAE classifies the impairment as a 90% instead of a 75% impairment, then the command to the flaperon is boosted by a factor of 10. This would cause the actuators, *as they are modeled in the simulation*, to rate saturate, since the actuator rate limiters are modeled *before* the integrators and position limiters. (It is because of this possibility that the recommendation is made in Chapter 5 to implement actuator rate saturation "flags" in the simulation). It is also pointed out to the reader that Lewis [26] encountered the same (and unexplained) kinds of phenomena in his study of dual, total impairments.

Second Impairment

	LS (75%)	RS (75%)	LF (75%)	RF (75%)	RUD (75%)	AOA (100%)	Q (100%)	A_n (100%)	P (100%)	R (100%)	A_y (100%)
LS (75%)	**fail251.250**	fail251.252	fail251.253	fail251.254	fail251.255	fail251.06	fail251.07	fail251.08	fail251.09	fail251.010	fail251.011
RS (75%)	fail252.251	**fail252.250**	fail252.253	fail252.254	fail252.255	fail252.06	fail252.07	fail252.08	fail252.09	fail252.010	fail252.011
LF (75%)	fail253.251	fail253.252	**fail253.250**	fail253.254	fail253.255	fail253.06	fail253.07	fail253.08	fail253.09	fail253.010	fail253.011
RF (75%)	fail254.251	fai254.252	fail254.253	**fail254.250**	fail254.255	fail254.06	fail254.07	fail254.08	fail254.09	fail254.010	fail254.011
RUD (75%)	fail255.251	fail255.252	fail255.253	fail255.254	**fail255.250**	fail255.06	fail255.07	fail255.08	fail255.09	fail255.010	fail255.011

Table H.2 A Listing of All State Plots Found in Appendix H.2 by Failure Case

H.2

dual-failure fail251.250 with reconfiguration
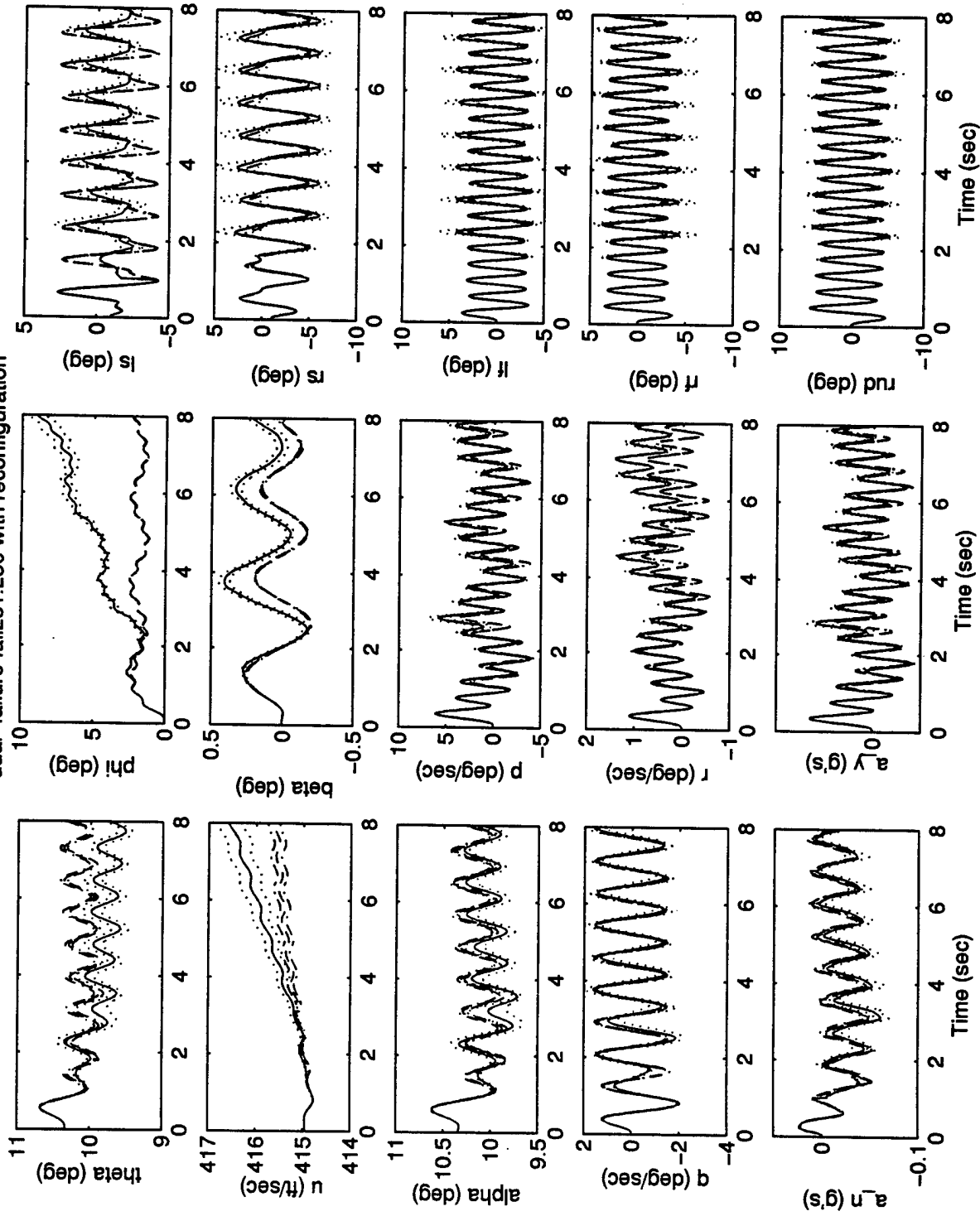
dual-failure fail251.252 with reconfiguration
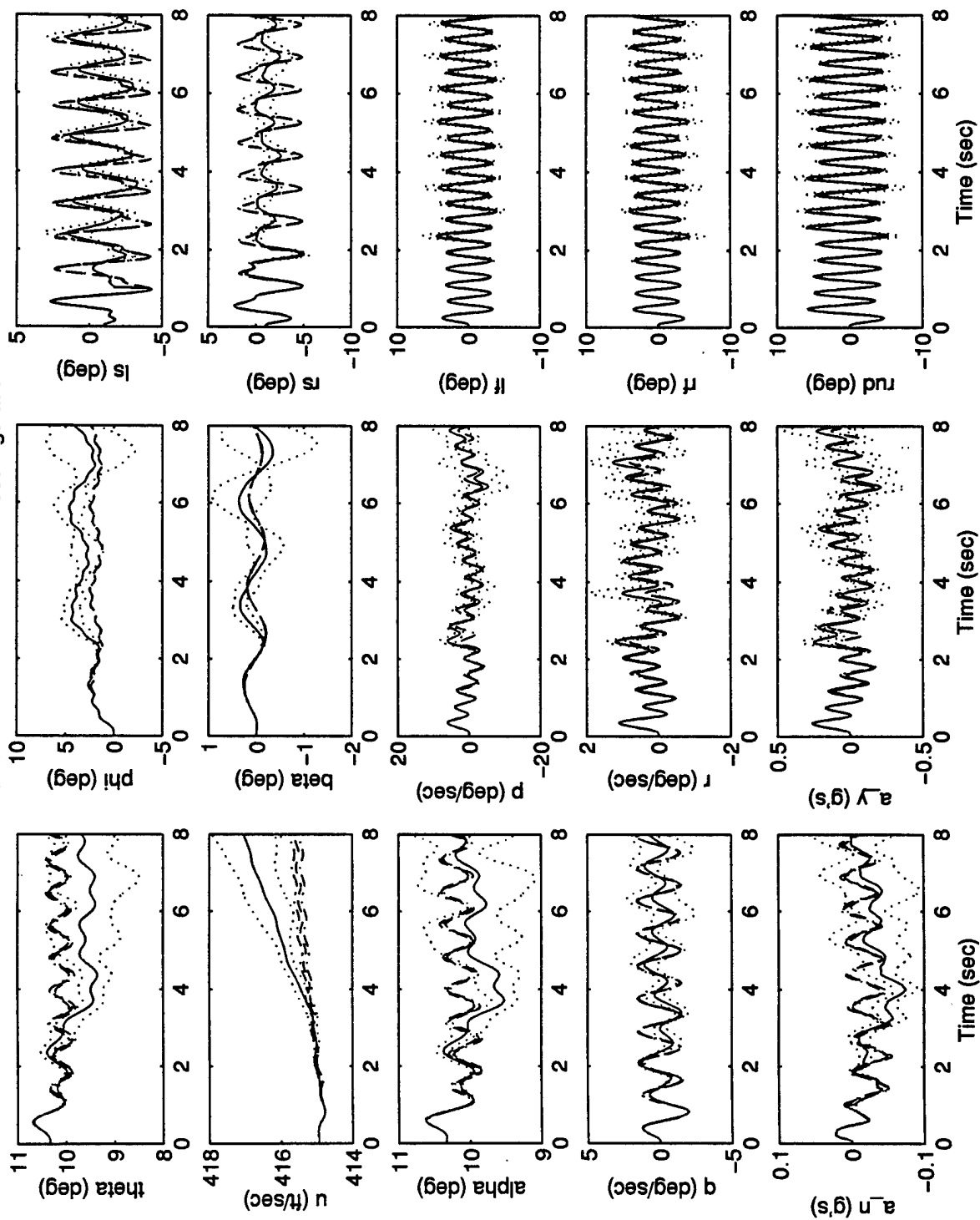
dual-failure fail251.253 with reconfiguration
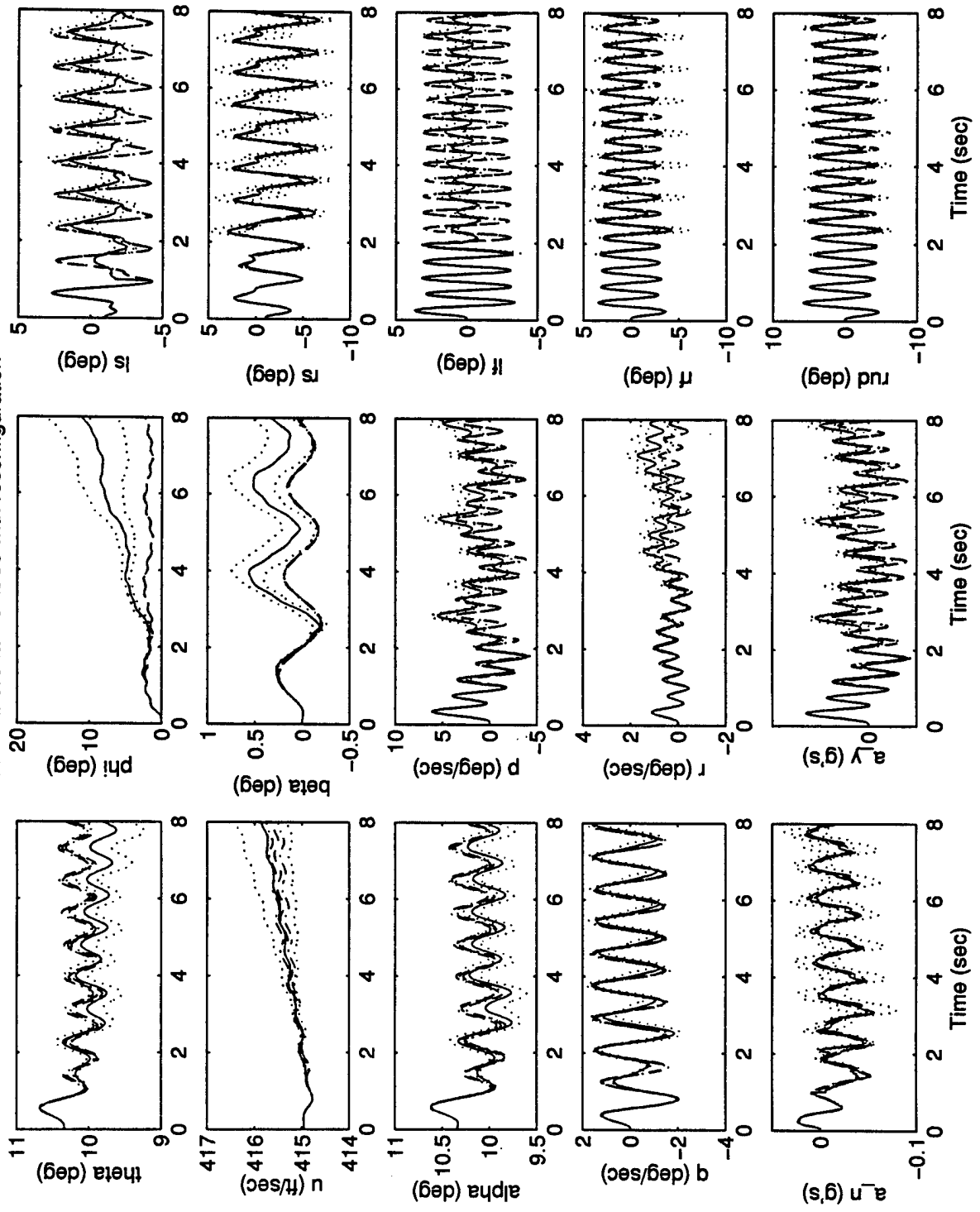
dual-failure fail251.254 with reconfiguration
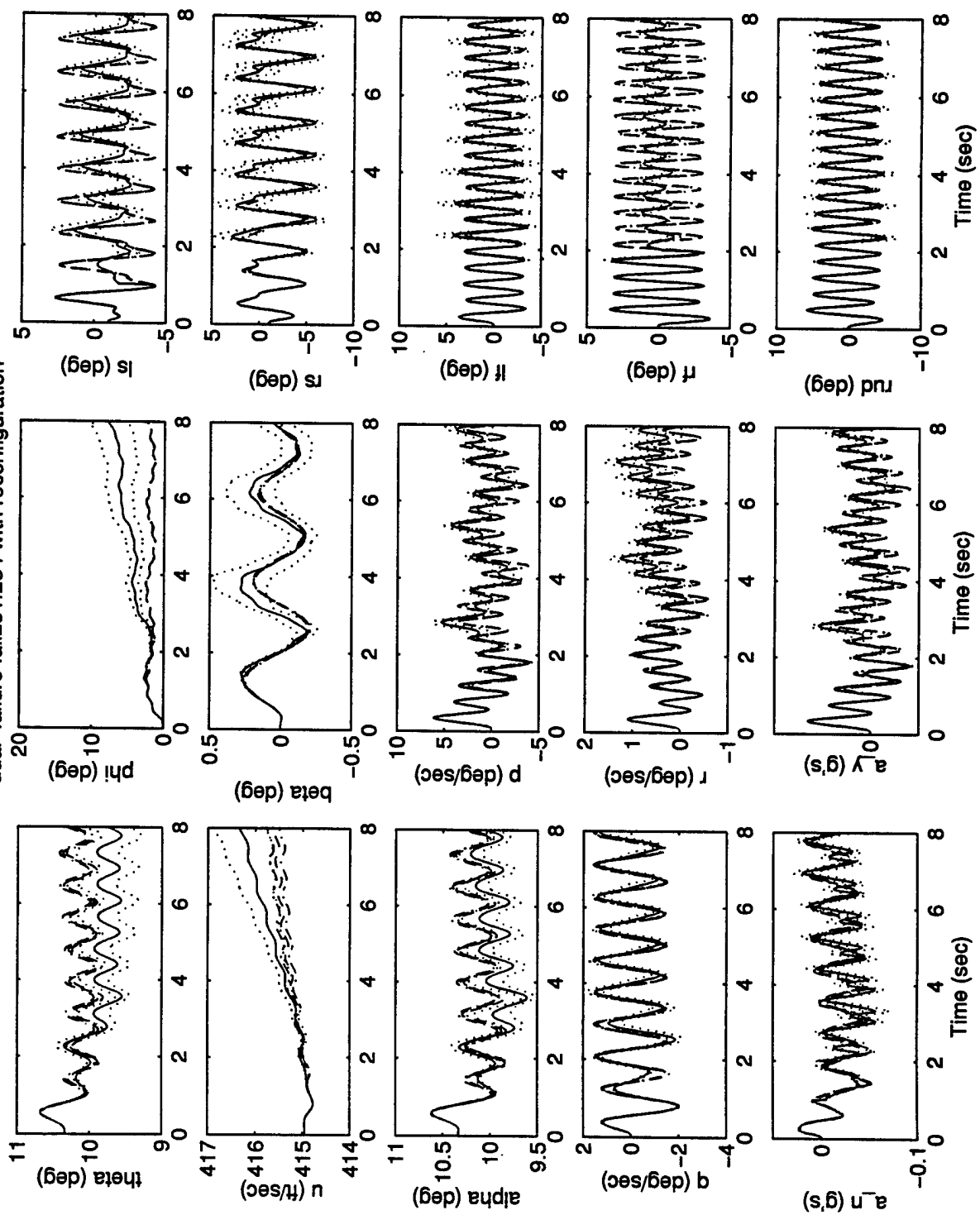
dual-failure fail251.255 with reconfiguration

dual-failure fail251.06 with reconfiguration
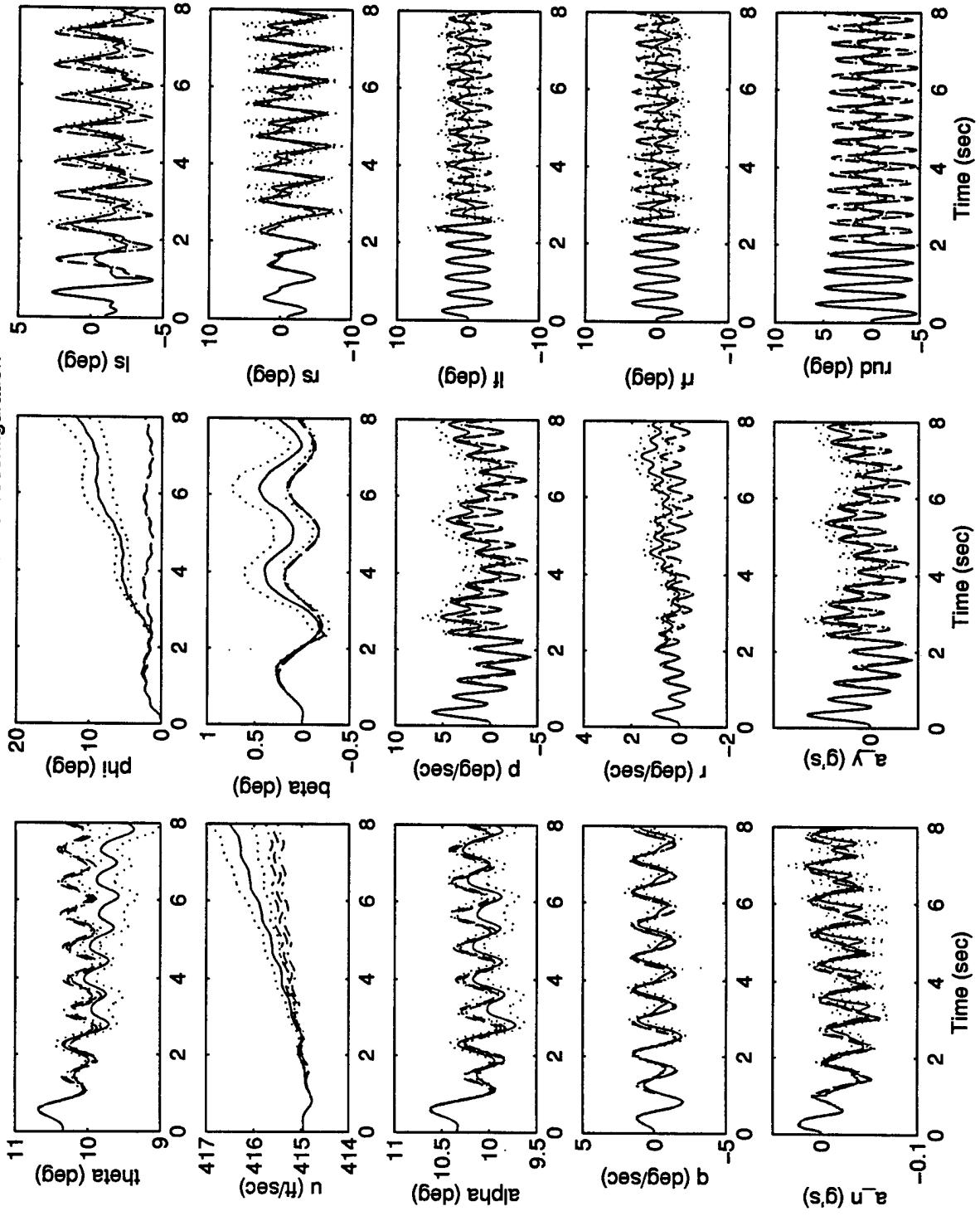
dual-failure fail251.07 with reconfiguration
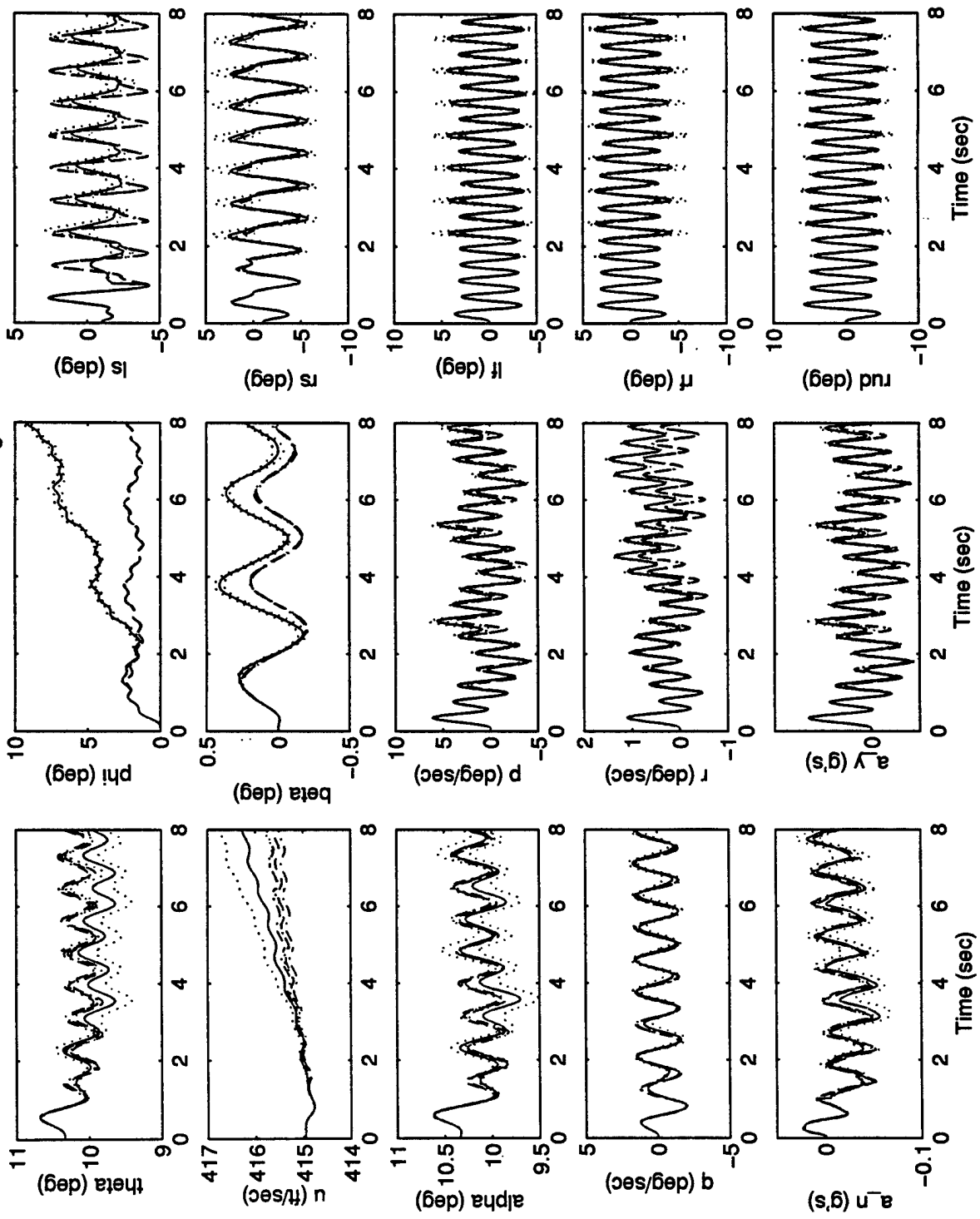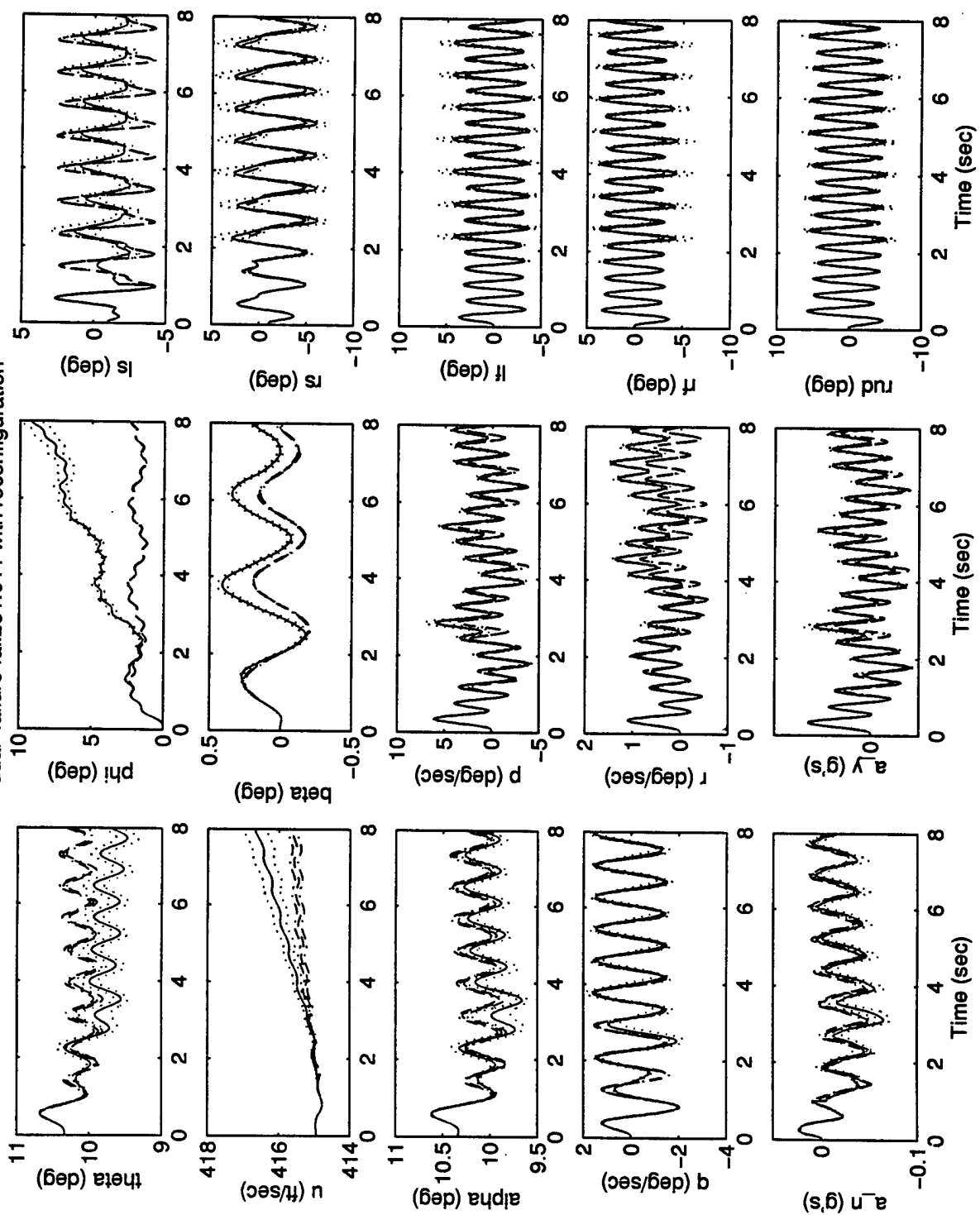
dual-failure fail251.08 with reconfiguration
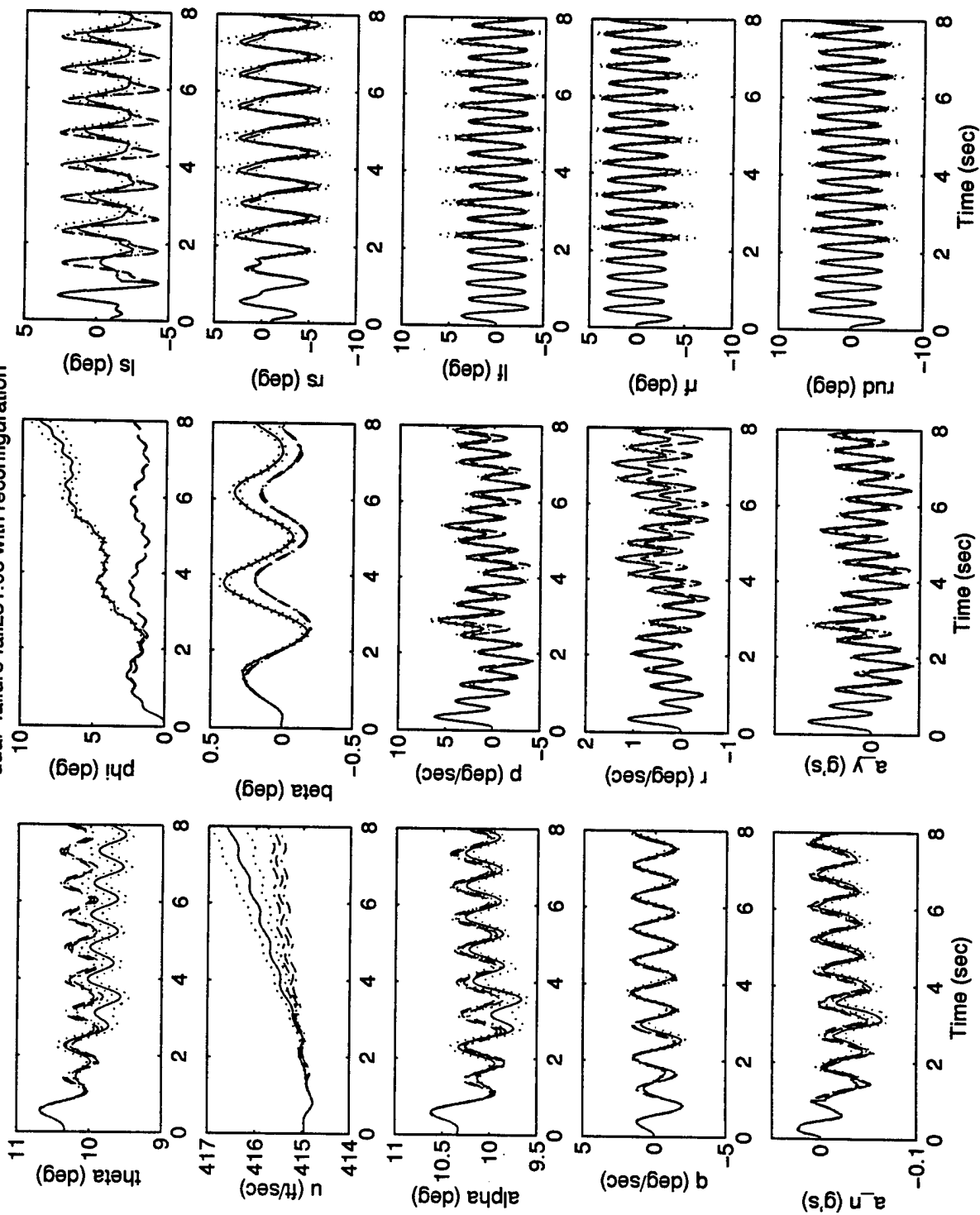
dual−failure fail251.09 with reconfiguration
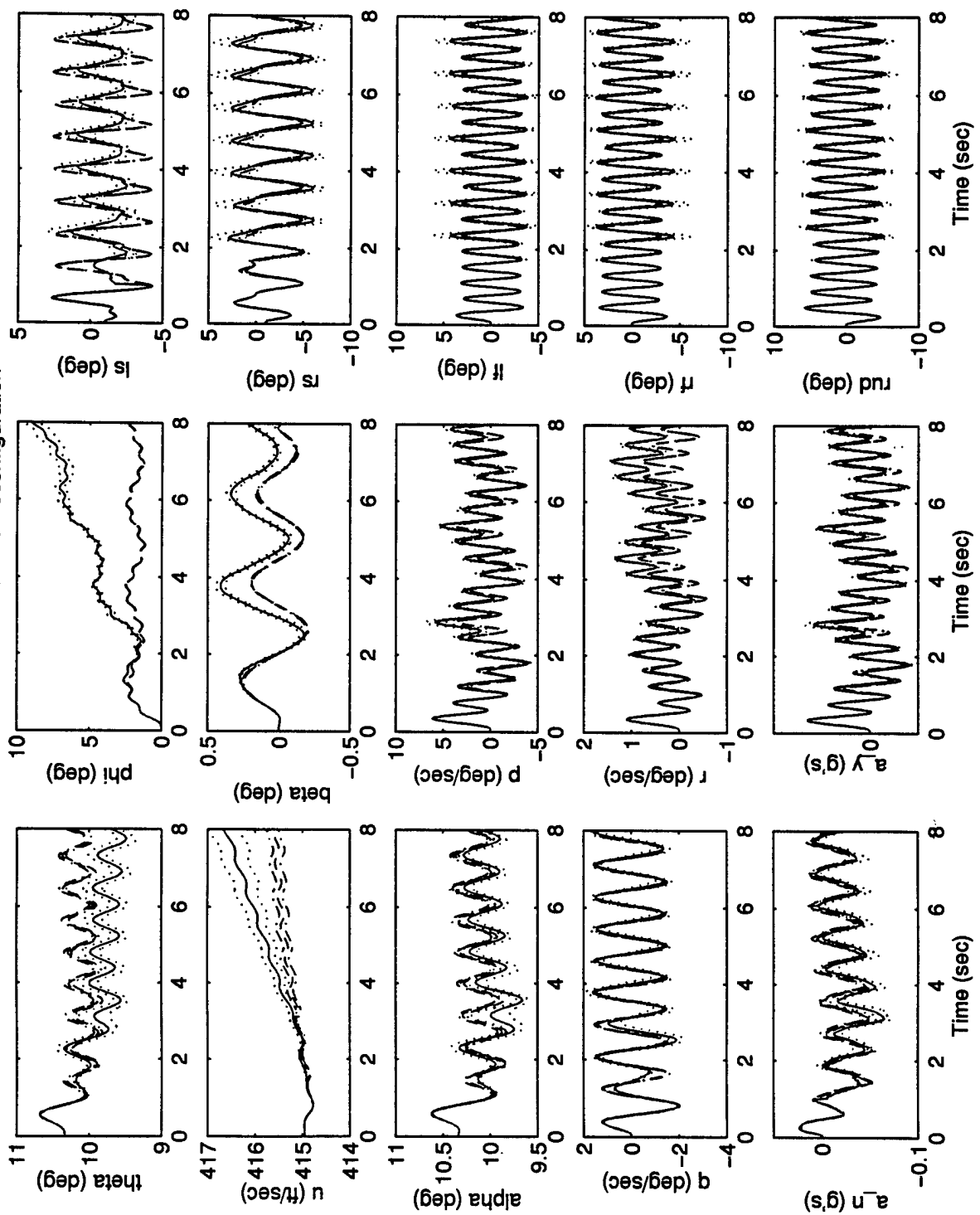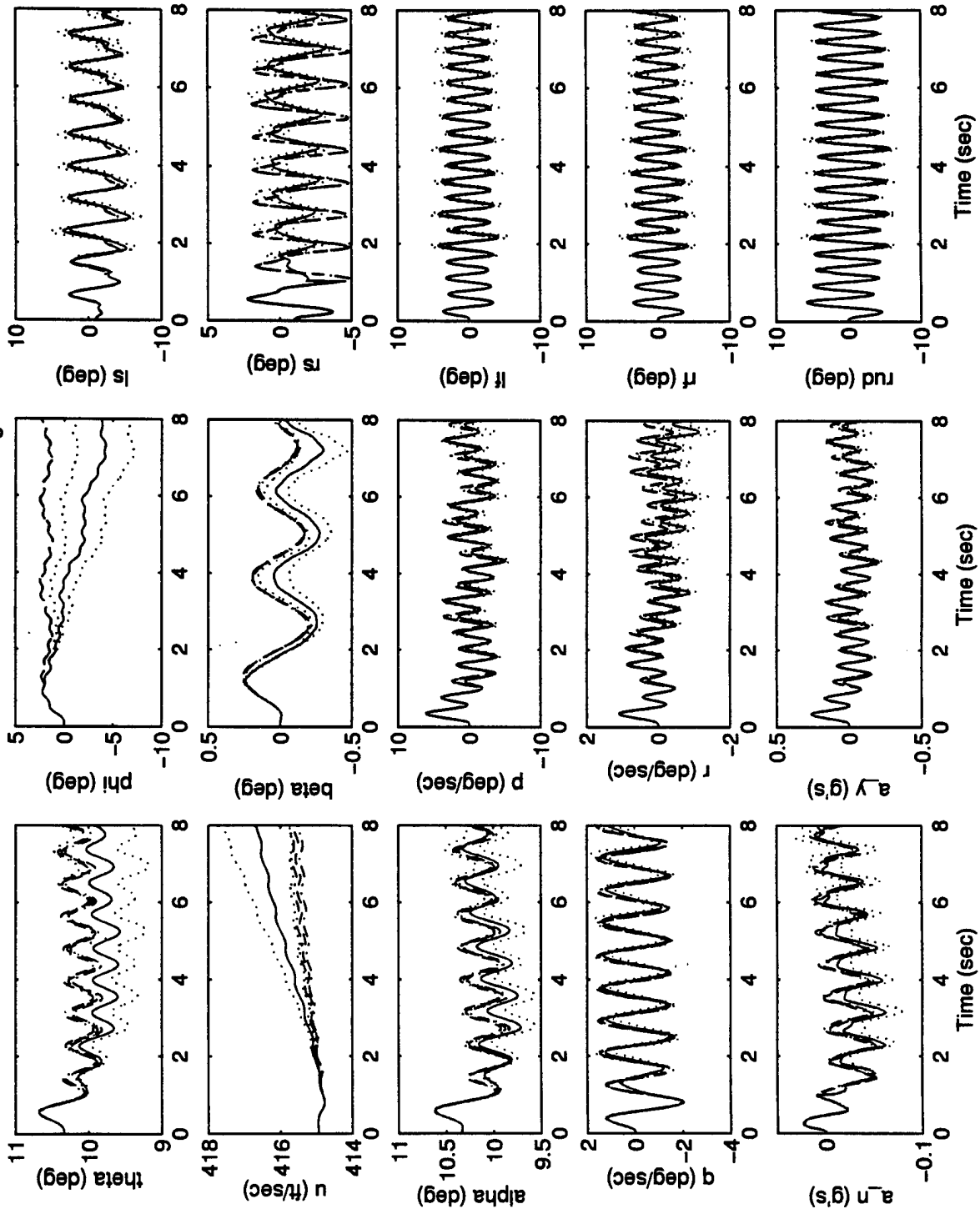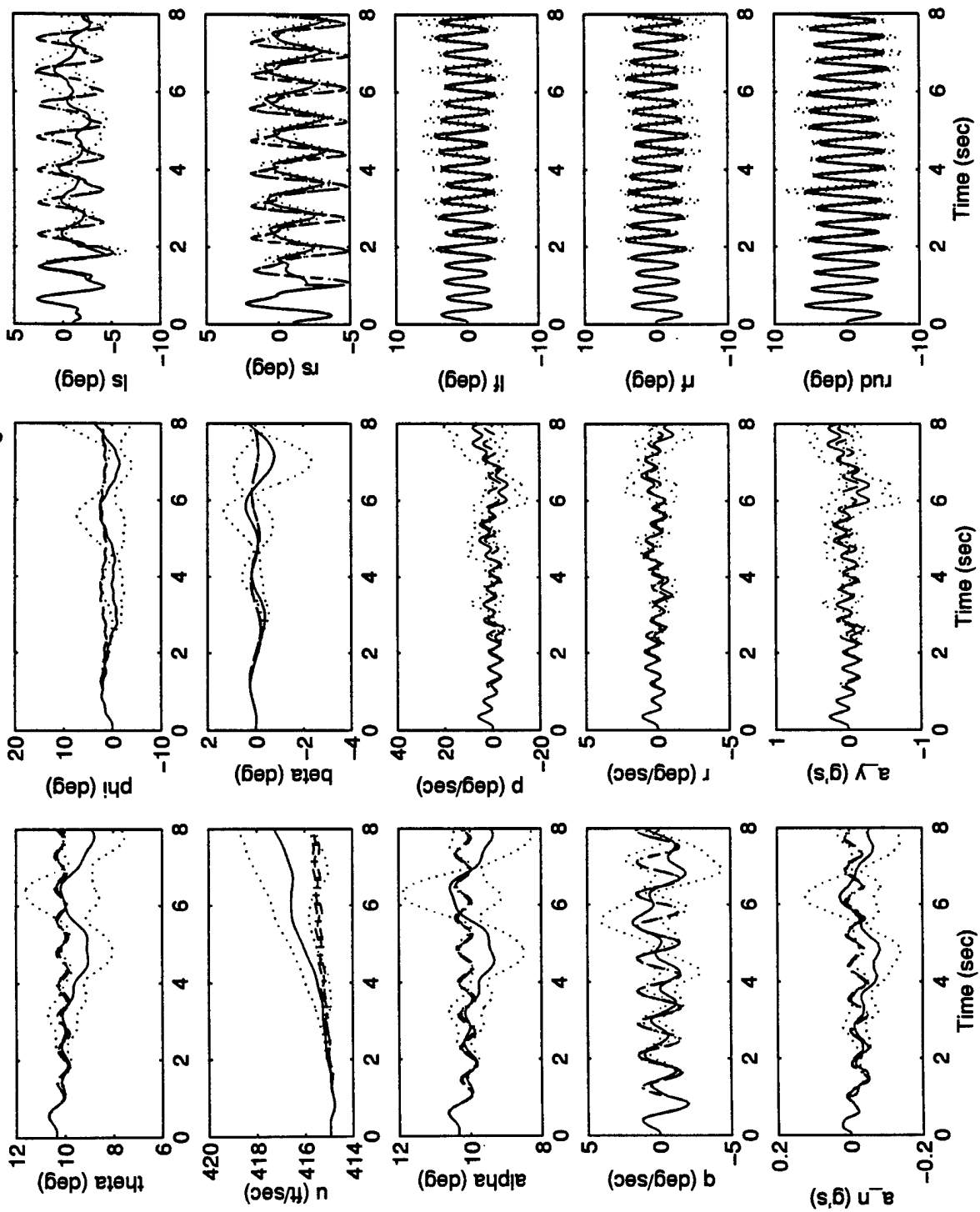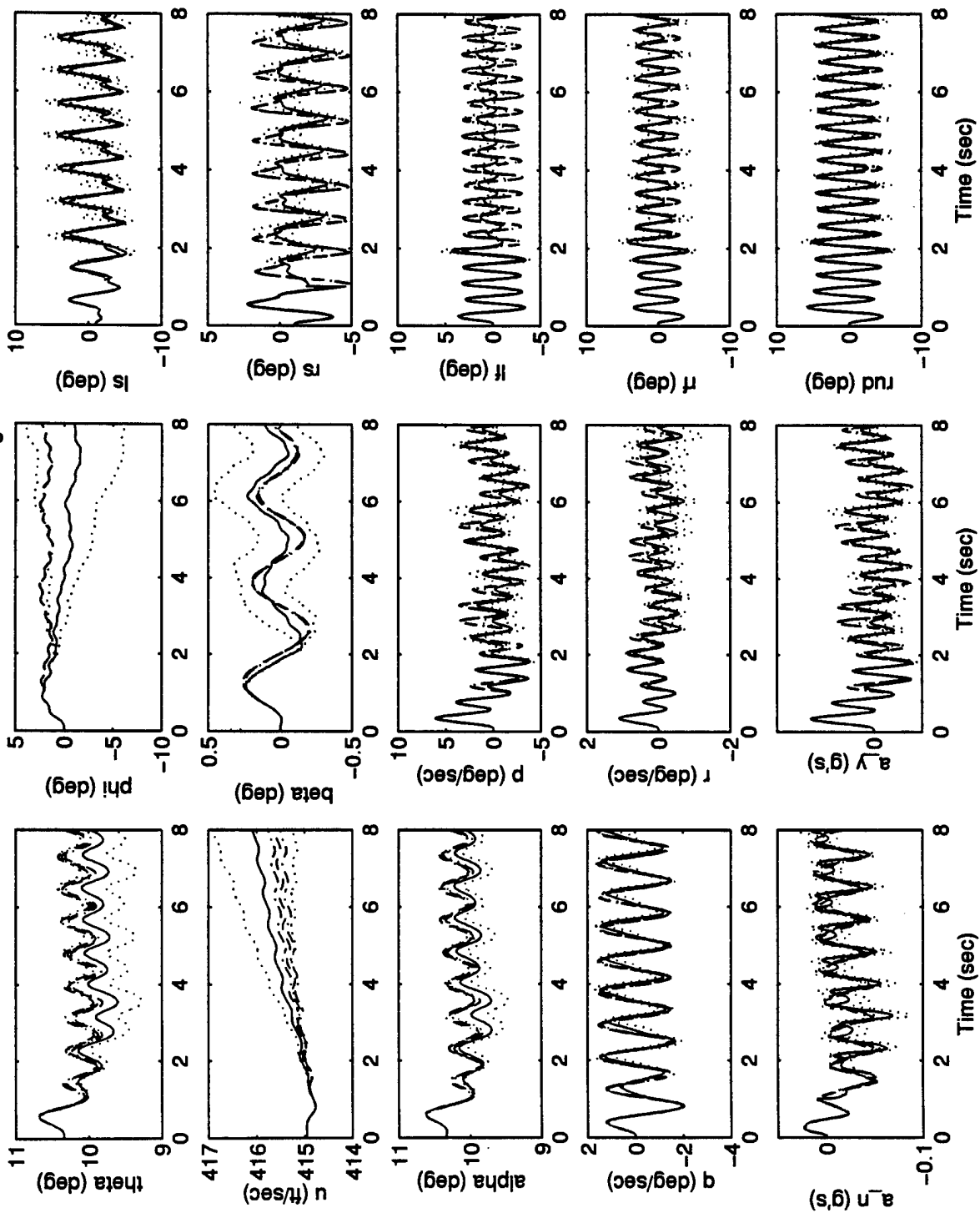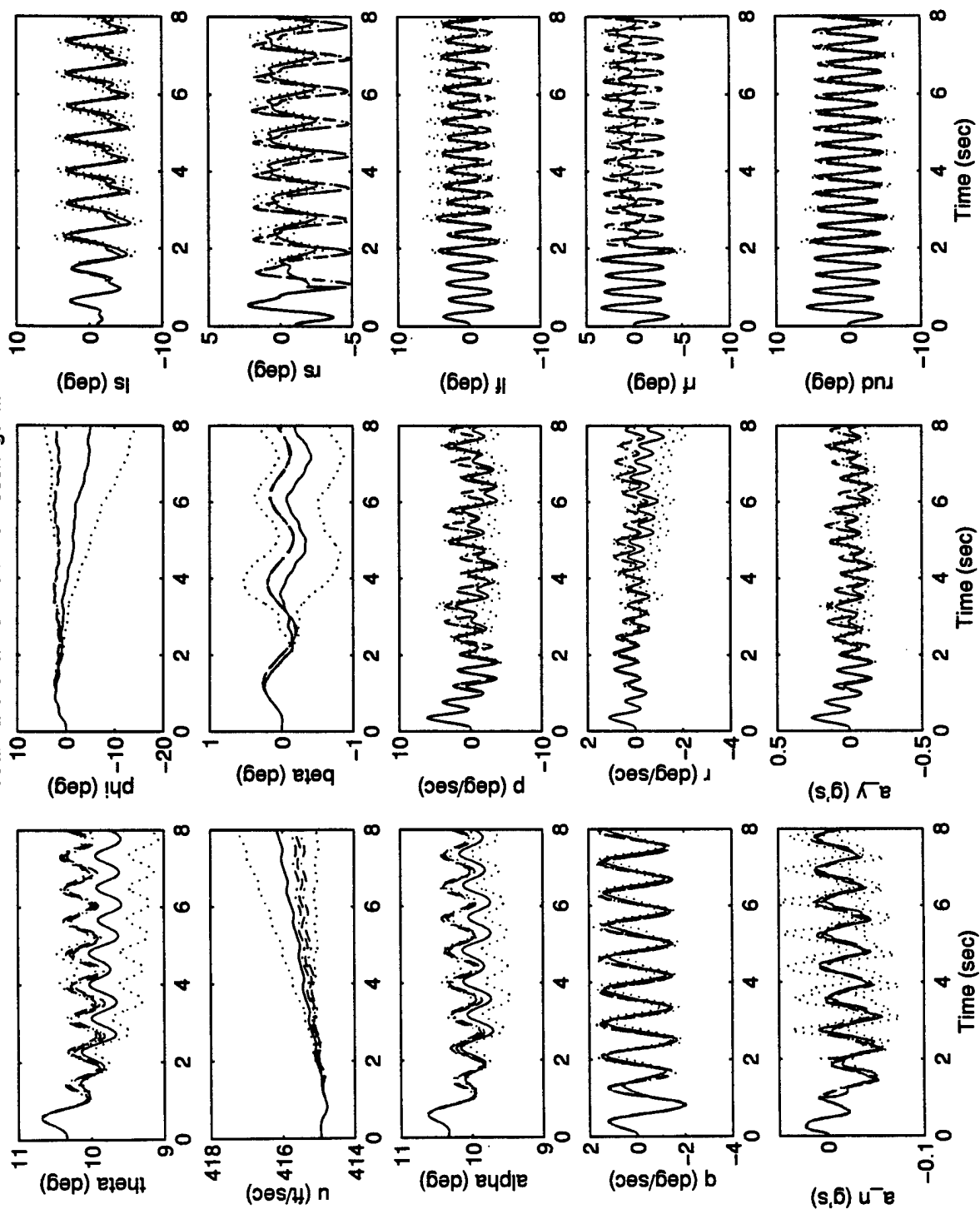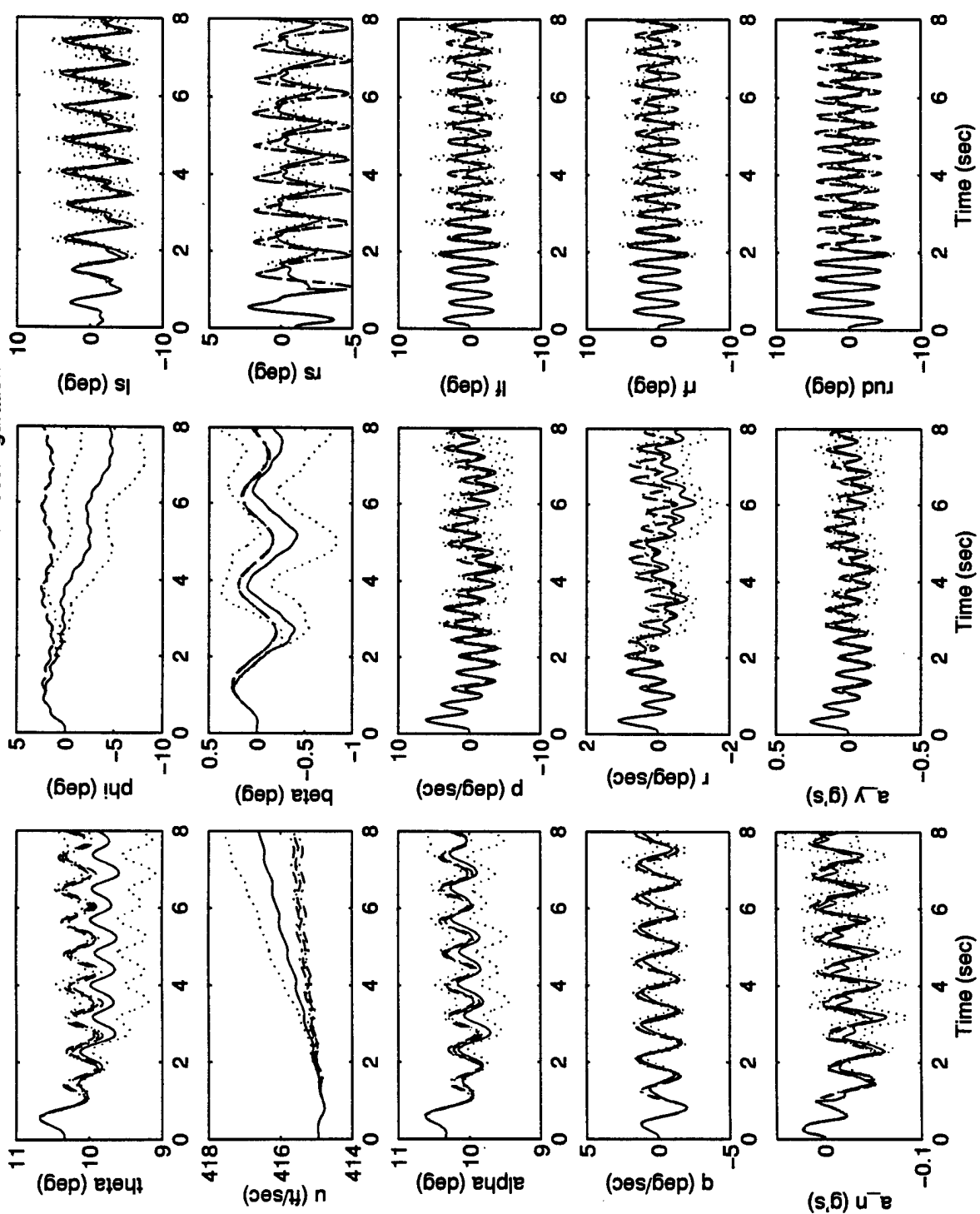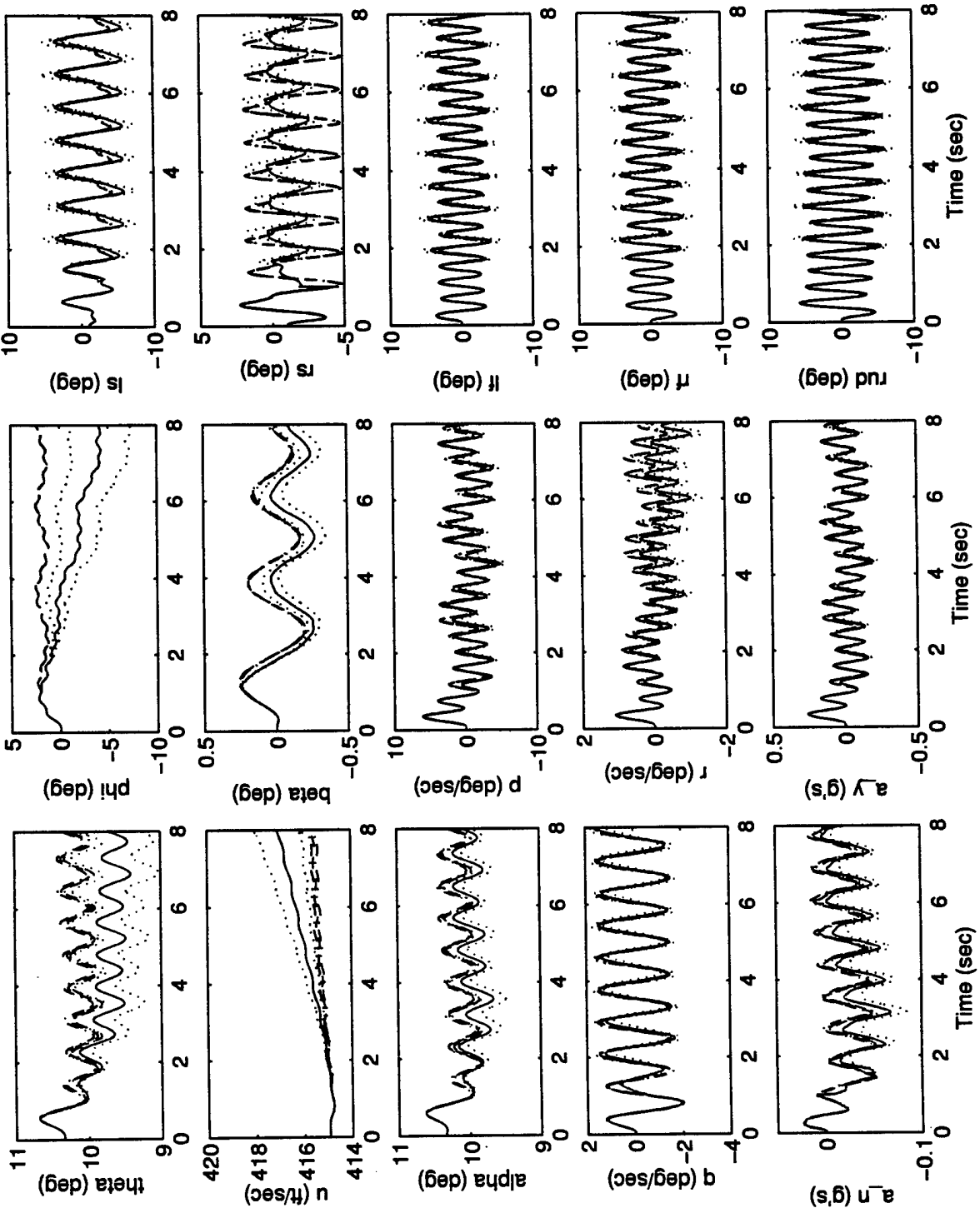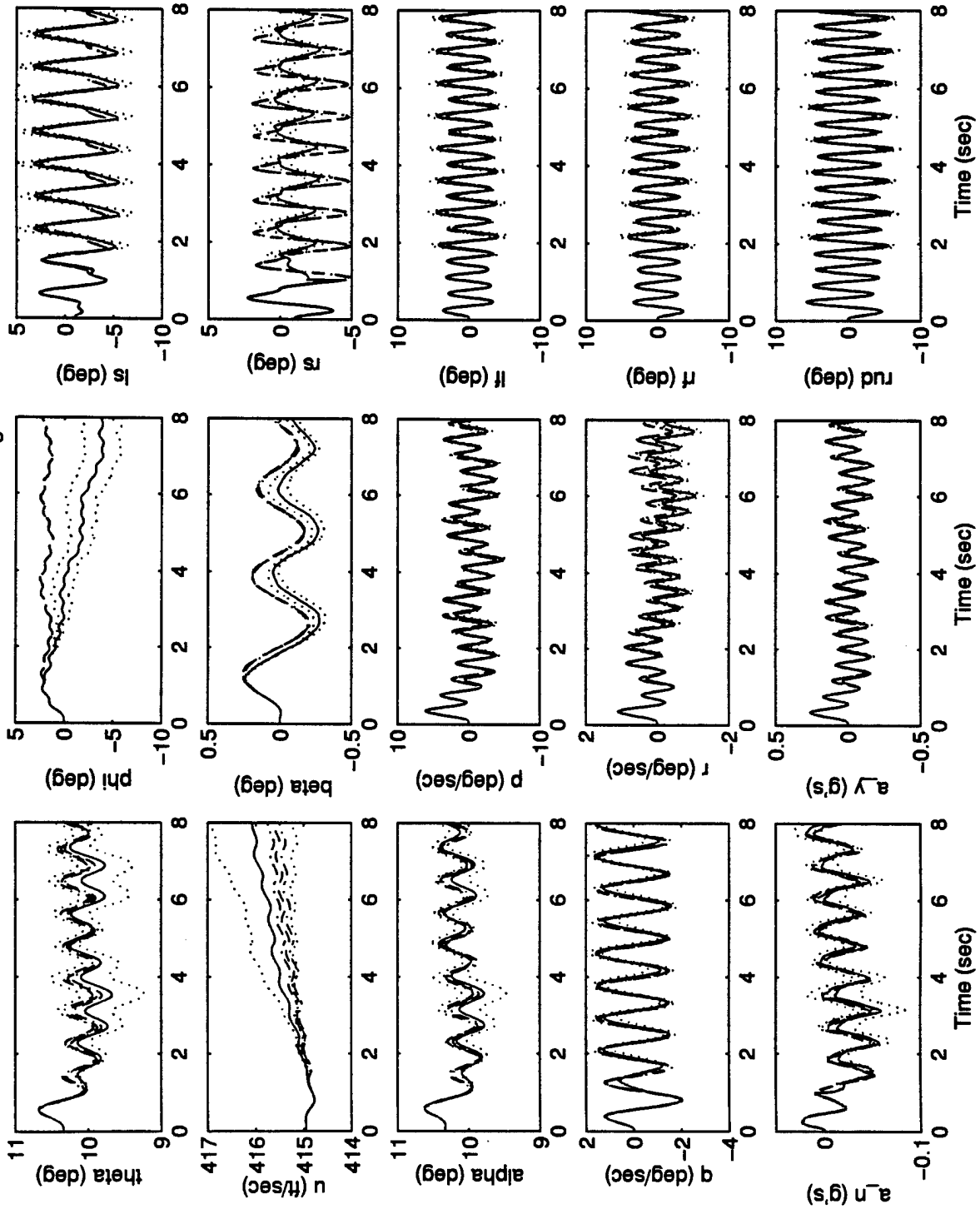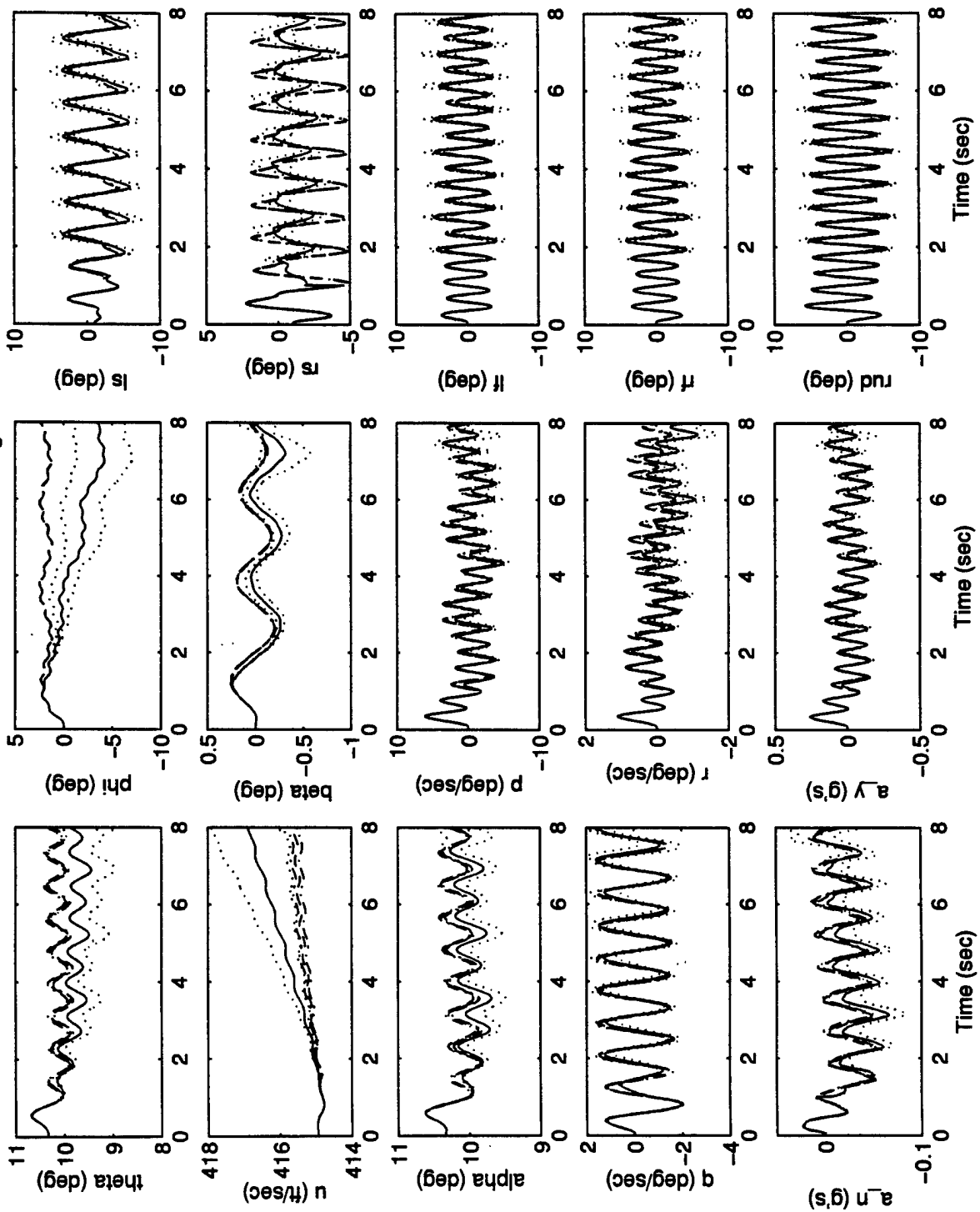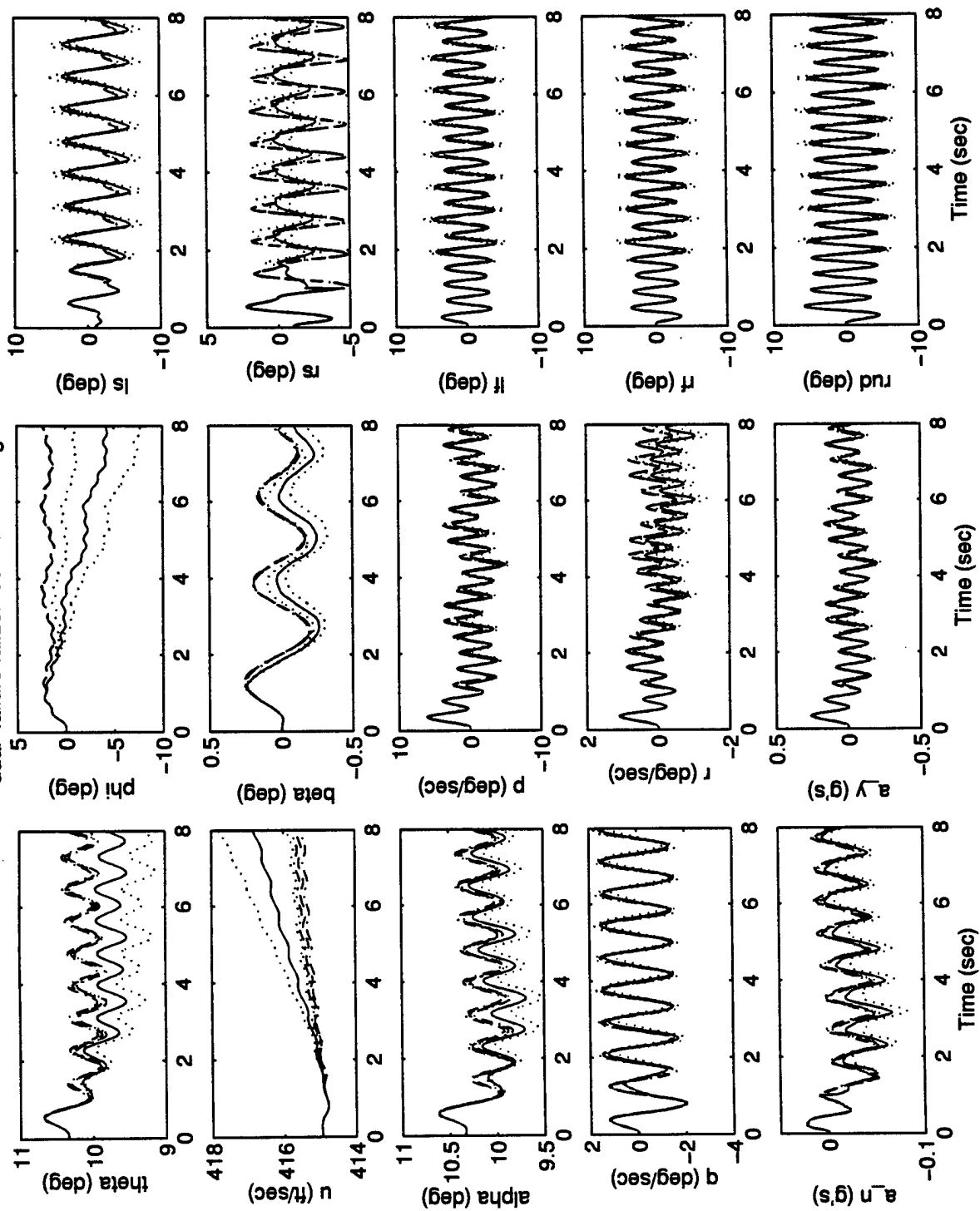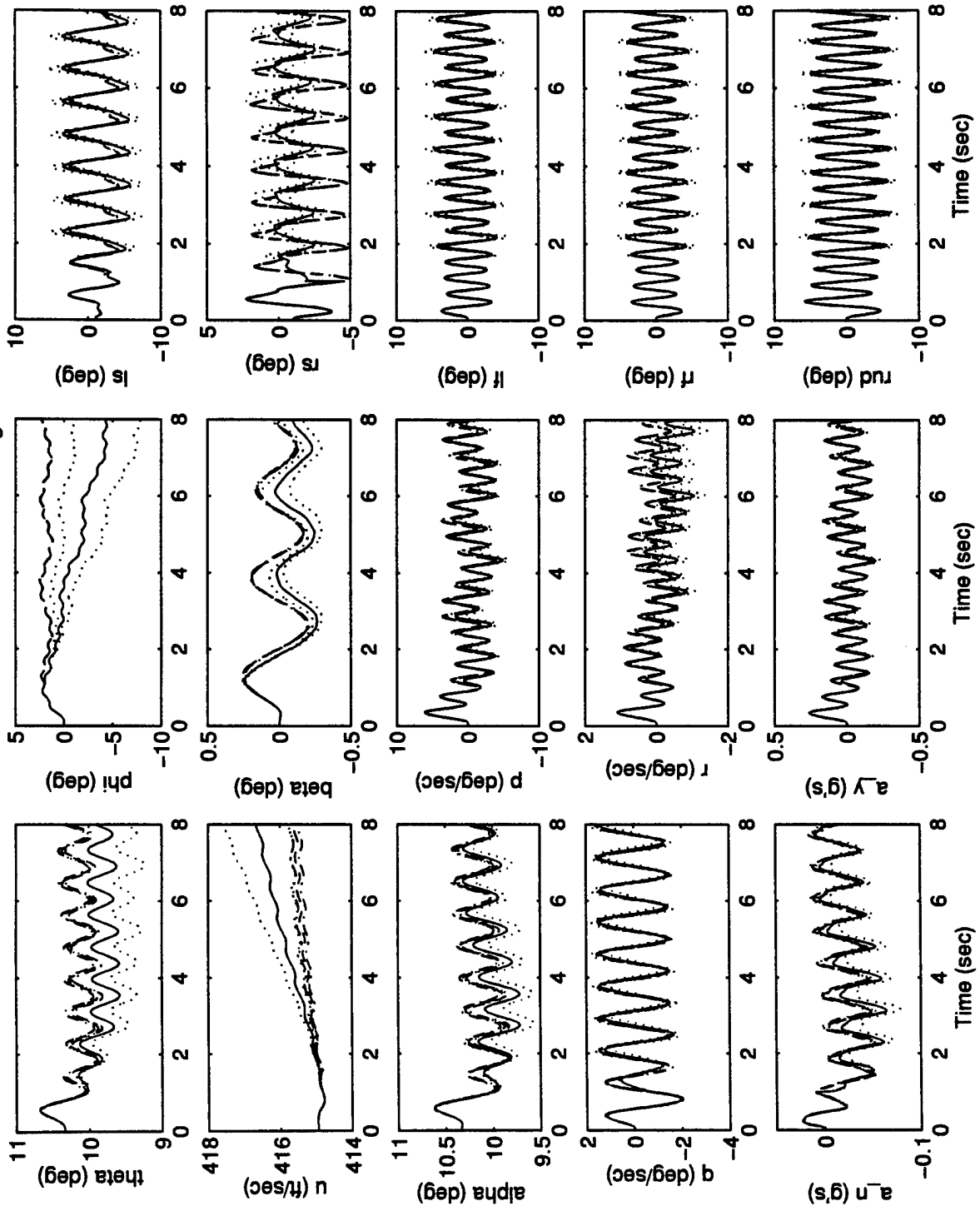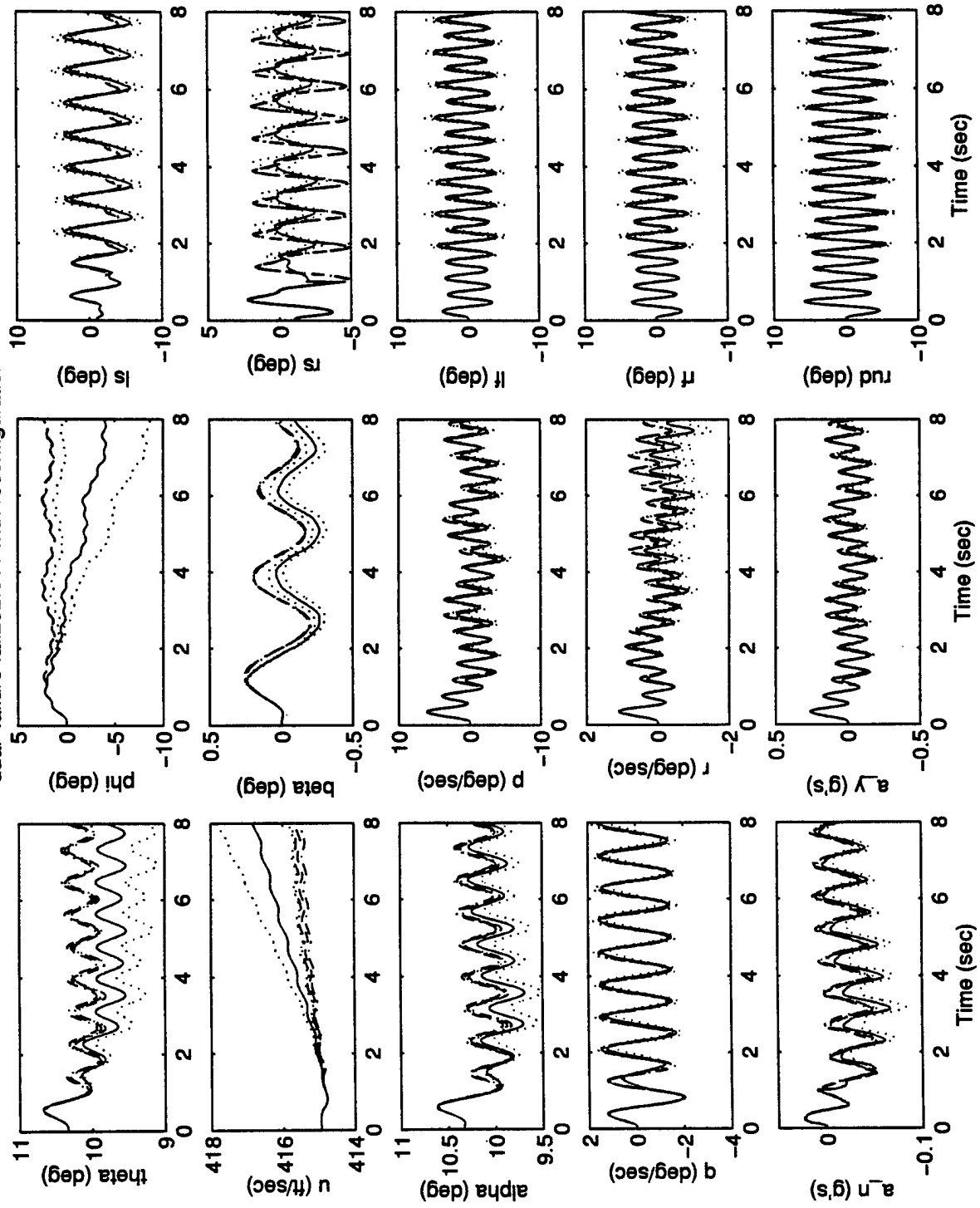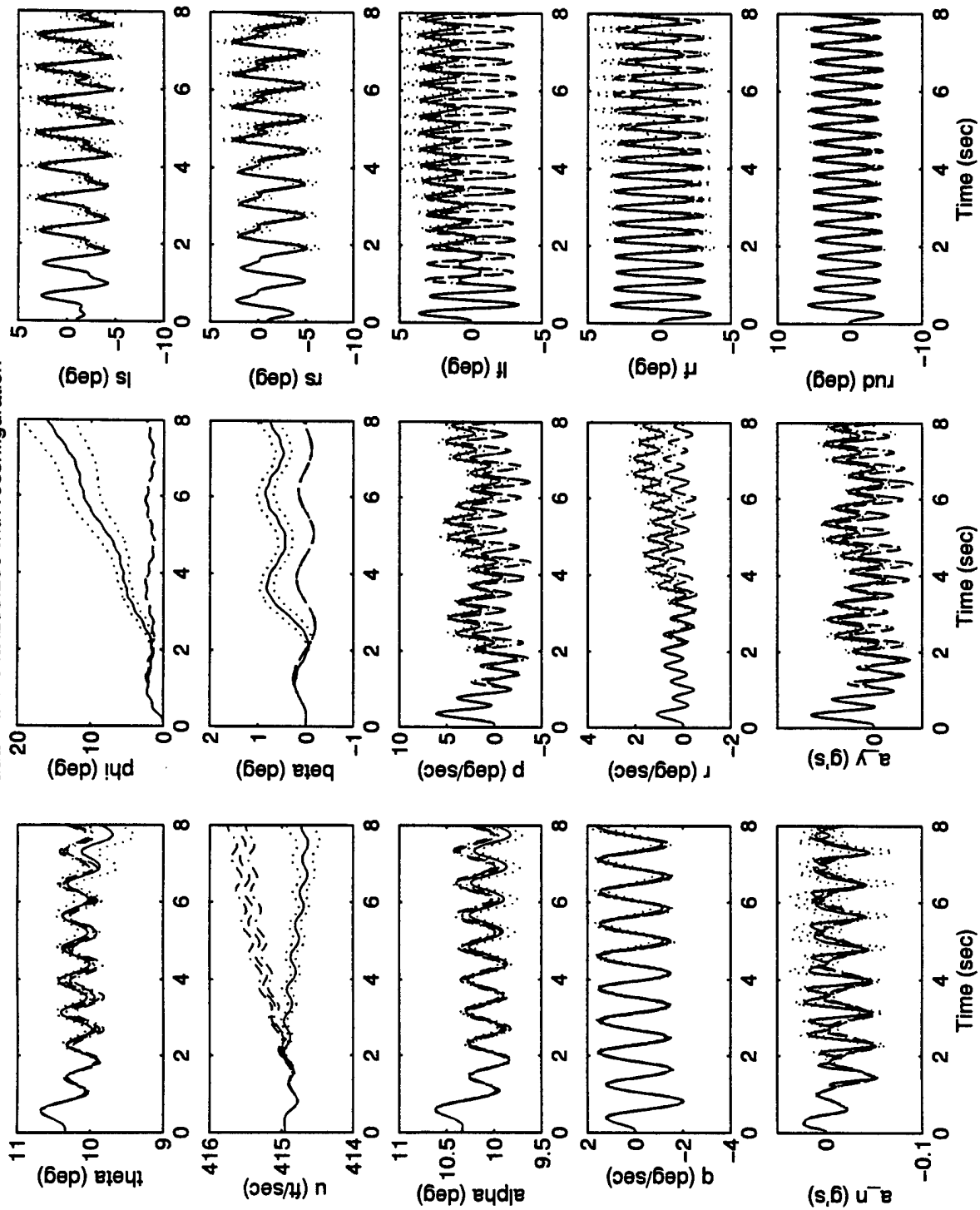
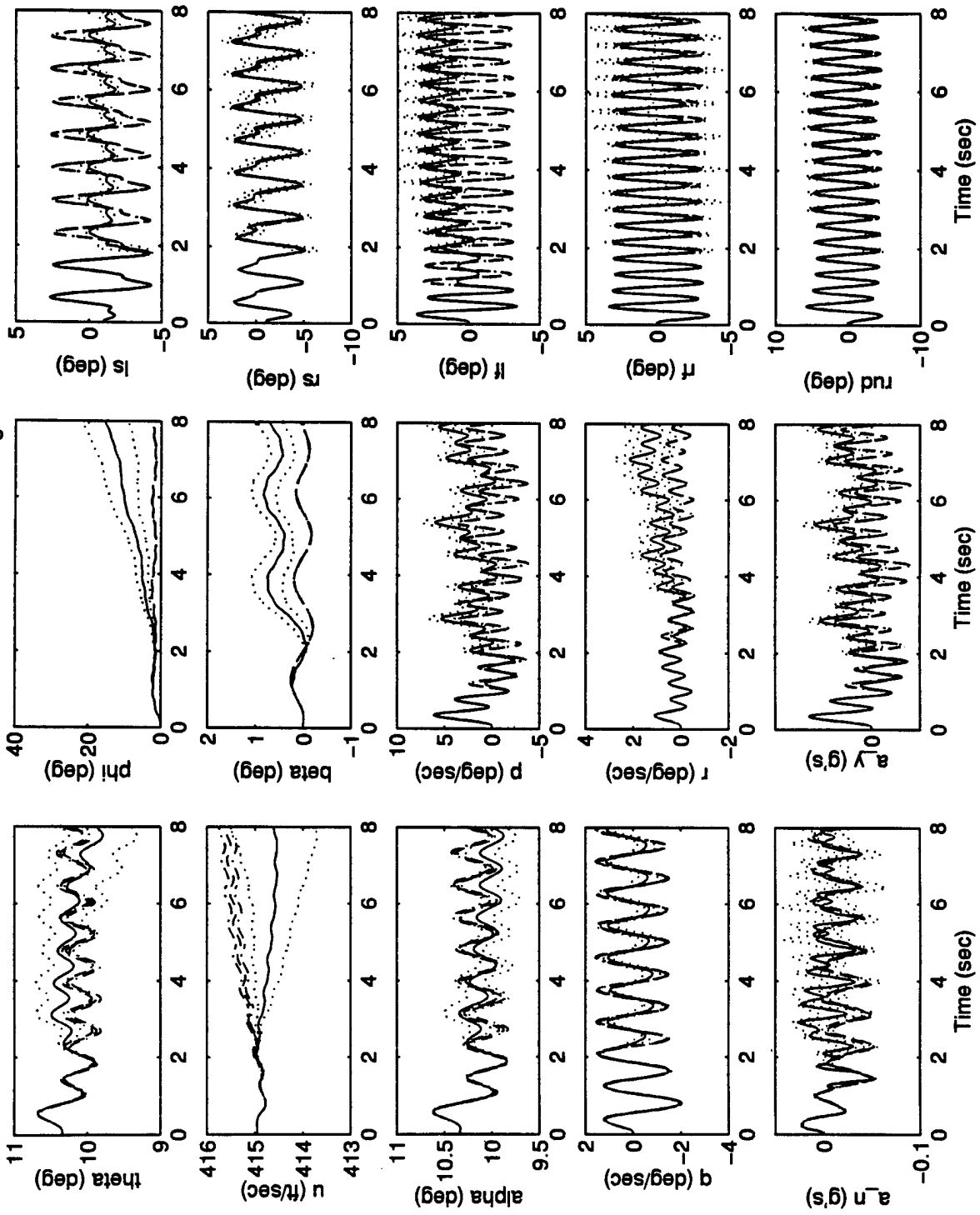dual-failure fail251.010 with reconfiguration
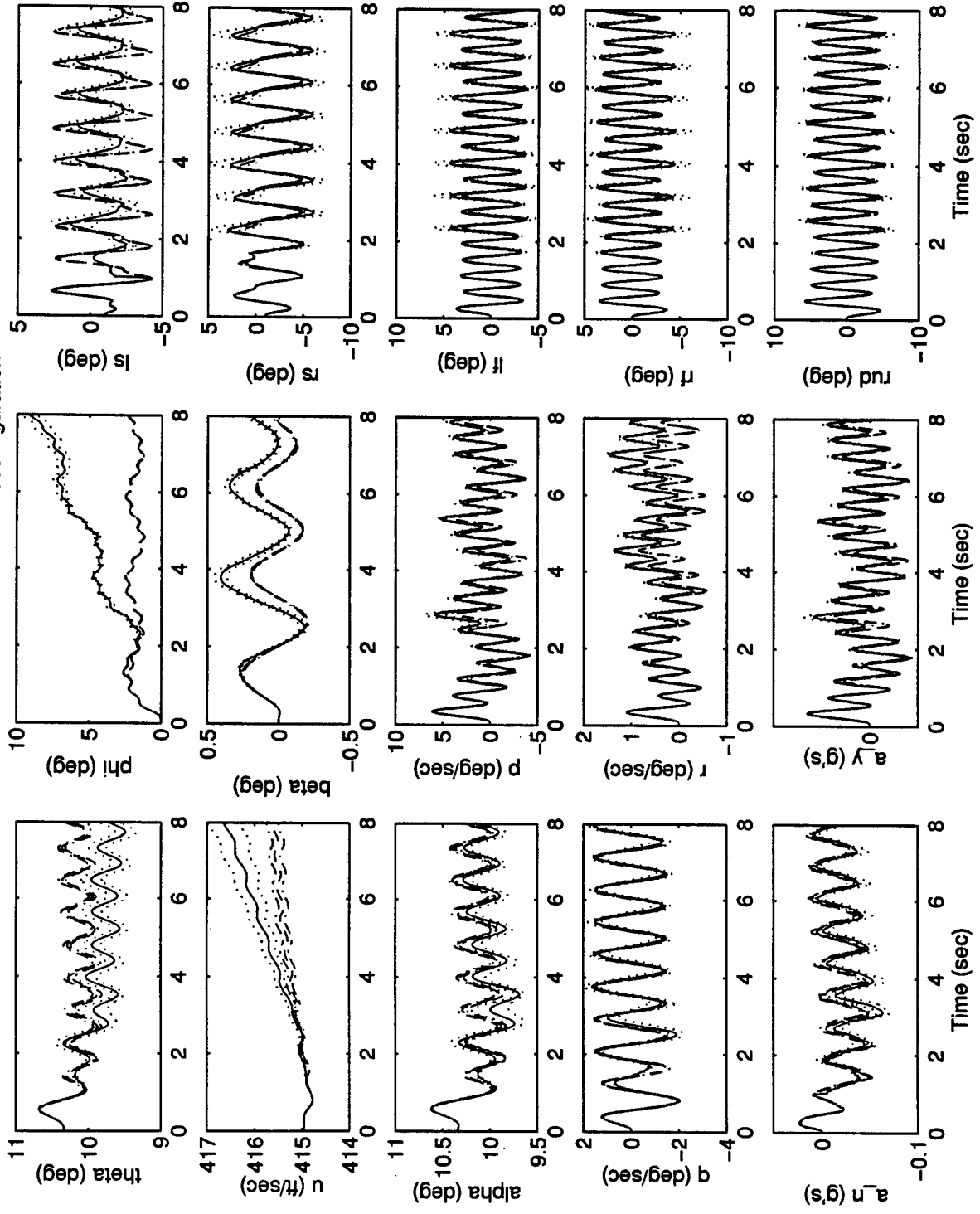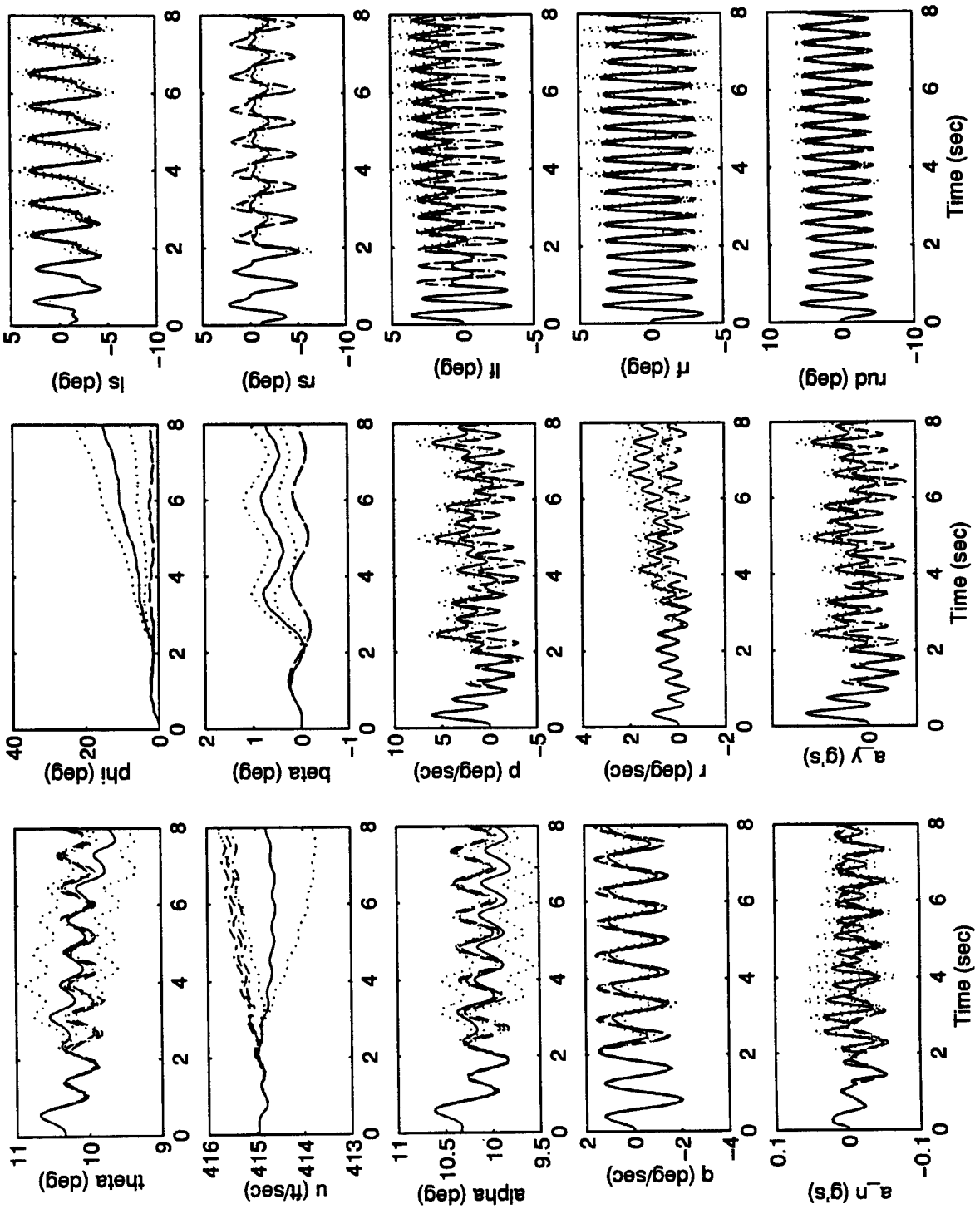
dual-failure fail251.011 with reconfiguration
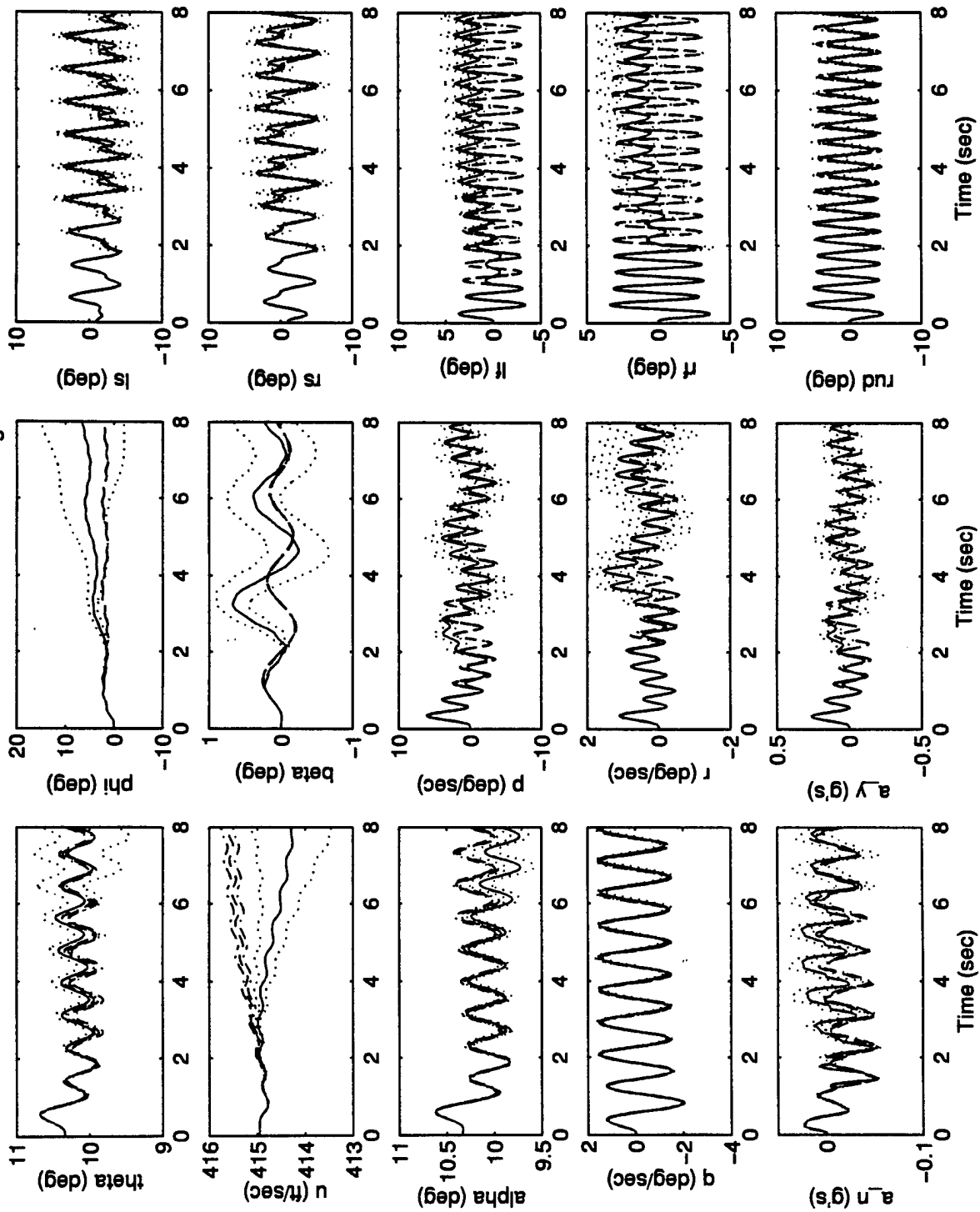
dual-failure fail252.250 with reconfiguration

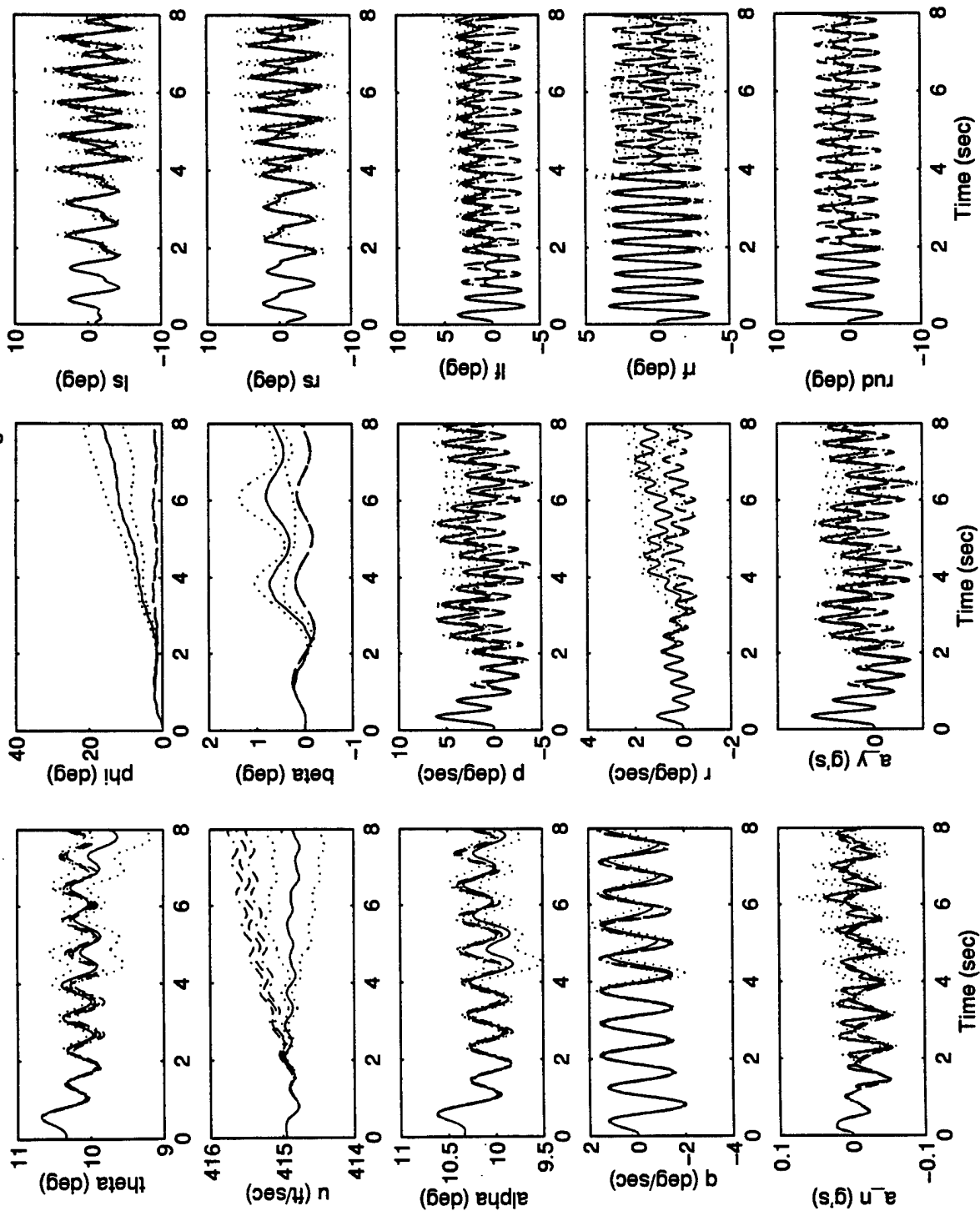dual–failure fail252.251 with reconfiguration

dual-failure fail252.253 with reconfiguration
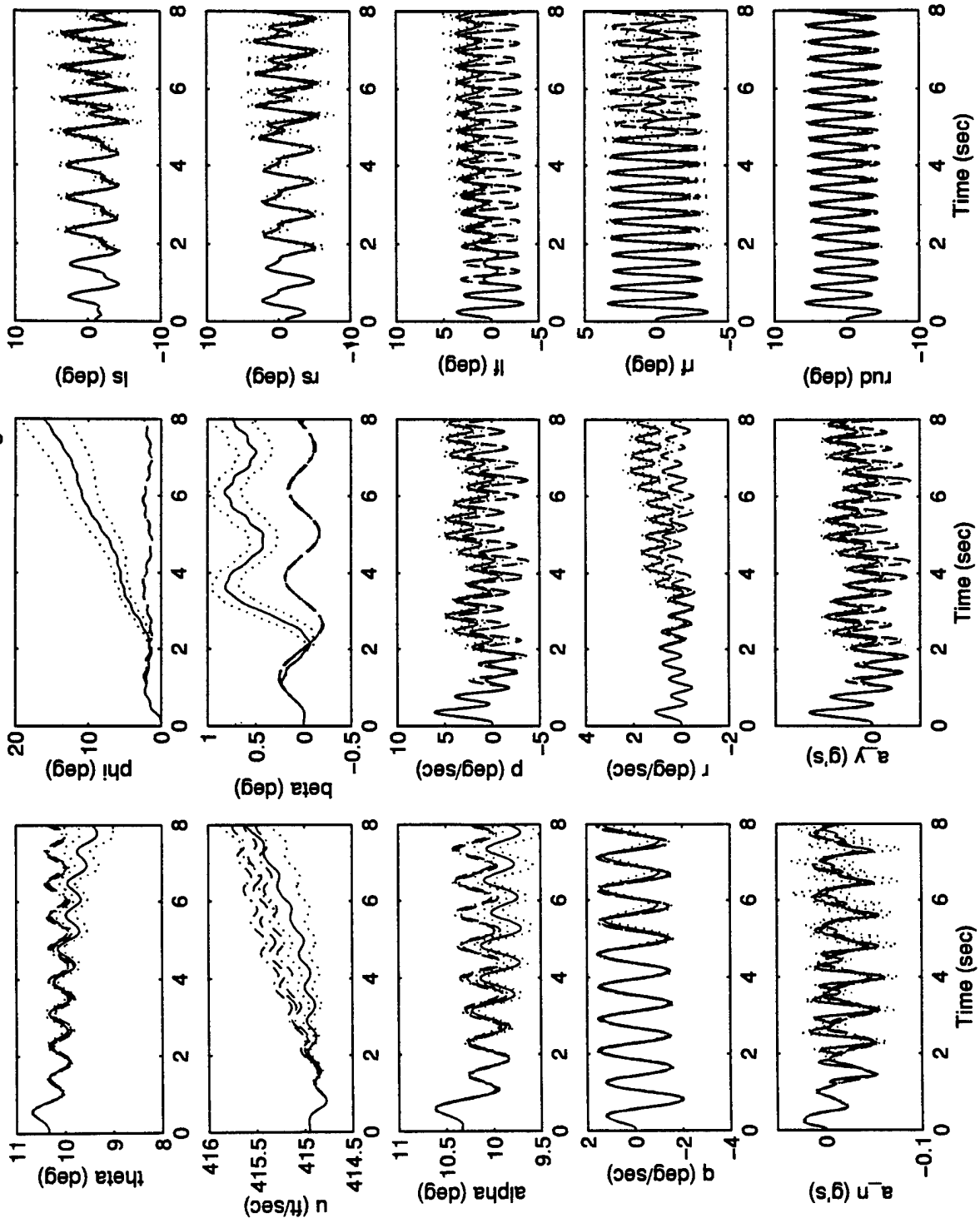
dual-failure fail252.254 with reconfiguration

dual-failure fail252.255 with reconfiguration

dual-failure fail252.06 with reconfiguration

dual-failure fail252.07 with reconfiguration

dual-failure fail252.08 with reconfiguration

dual-failure fail252.09 with reconfiguration

dual-failure fail252.010 with reconfiguration

dual-failure fail252.011 with reconfiguration

dual-failure fail253.250 with reconfiguration

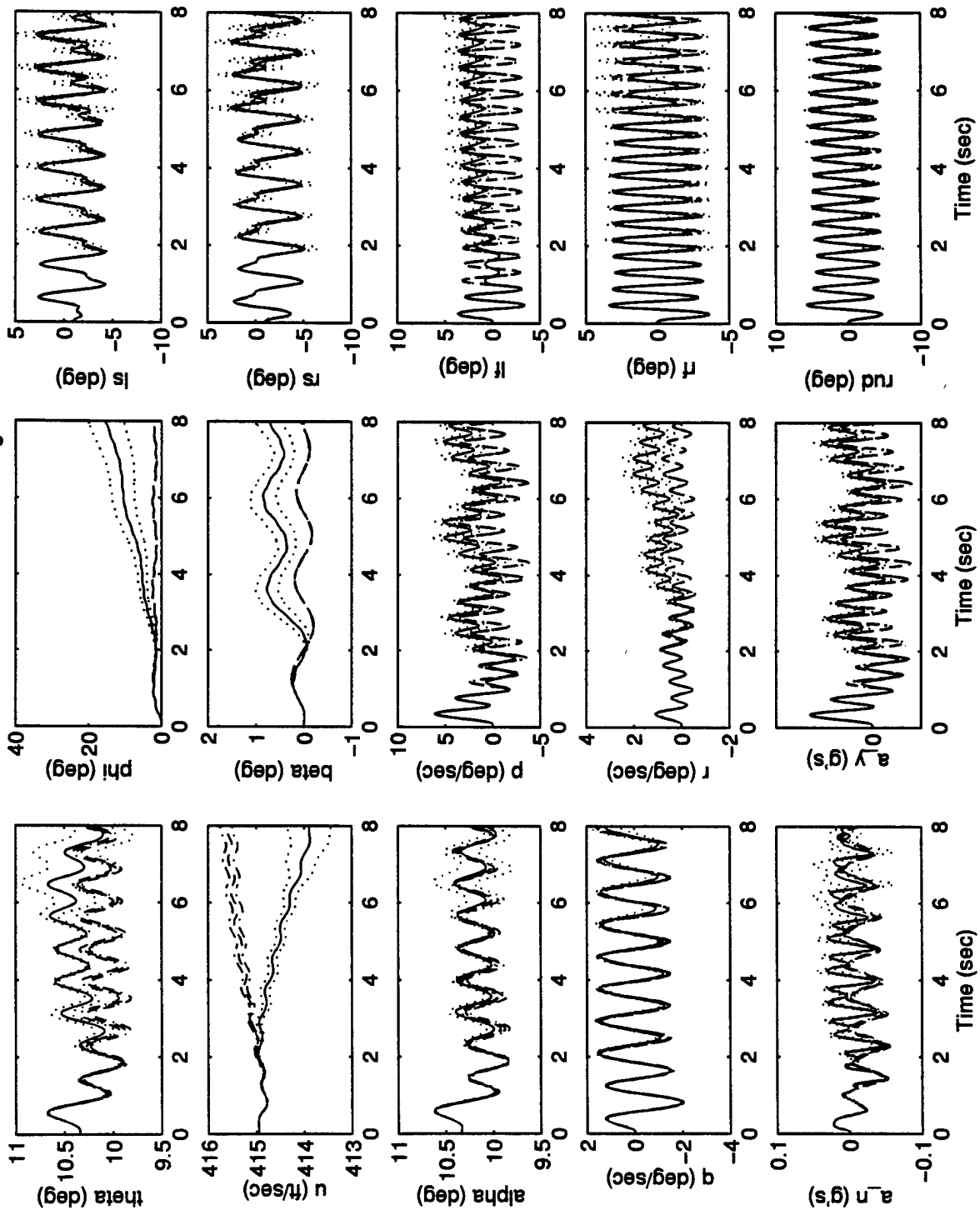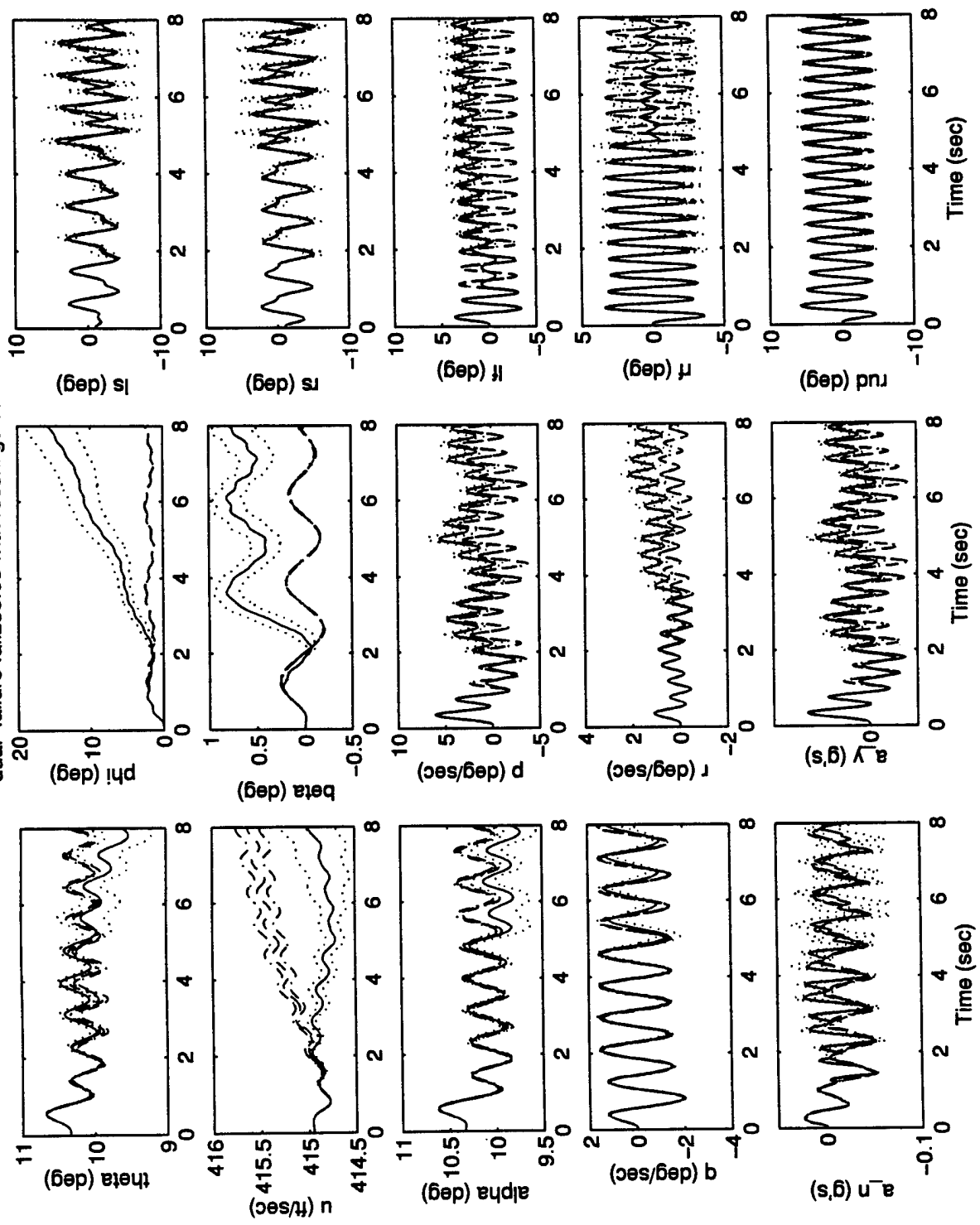dual-failure fail253.251 with reconfiguration

theta (deg)
u (ft/sec)
alpha (deg)
q (deg/sec)
a_n (g's)

phi (deg)
beta (deg)
p (deg/sec)
r (deg/sec)
a_y (g's)

ls (deg)
rs (deg)
lf (deg)
rf (deg)
rud (deg)

Time (sec)

dual-failure fail253.252 with reconfiguration

ls (deg) | rs (deg) | lf (deg) | rf (deg) | rud (deg)

phi (deg) | beta (deg) | p (deg/sec) | r (deg/sec) | a_y (g's)

theta (deg) | u (ft/sec) | alpha (deg) | q (deg/sec) | a_n (g's)

Time (sec)

dual-failure fail253.254 with reconfiguration

dual-failure fail253.255 with reconfiguration

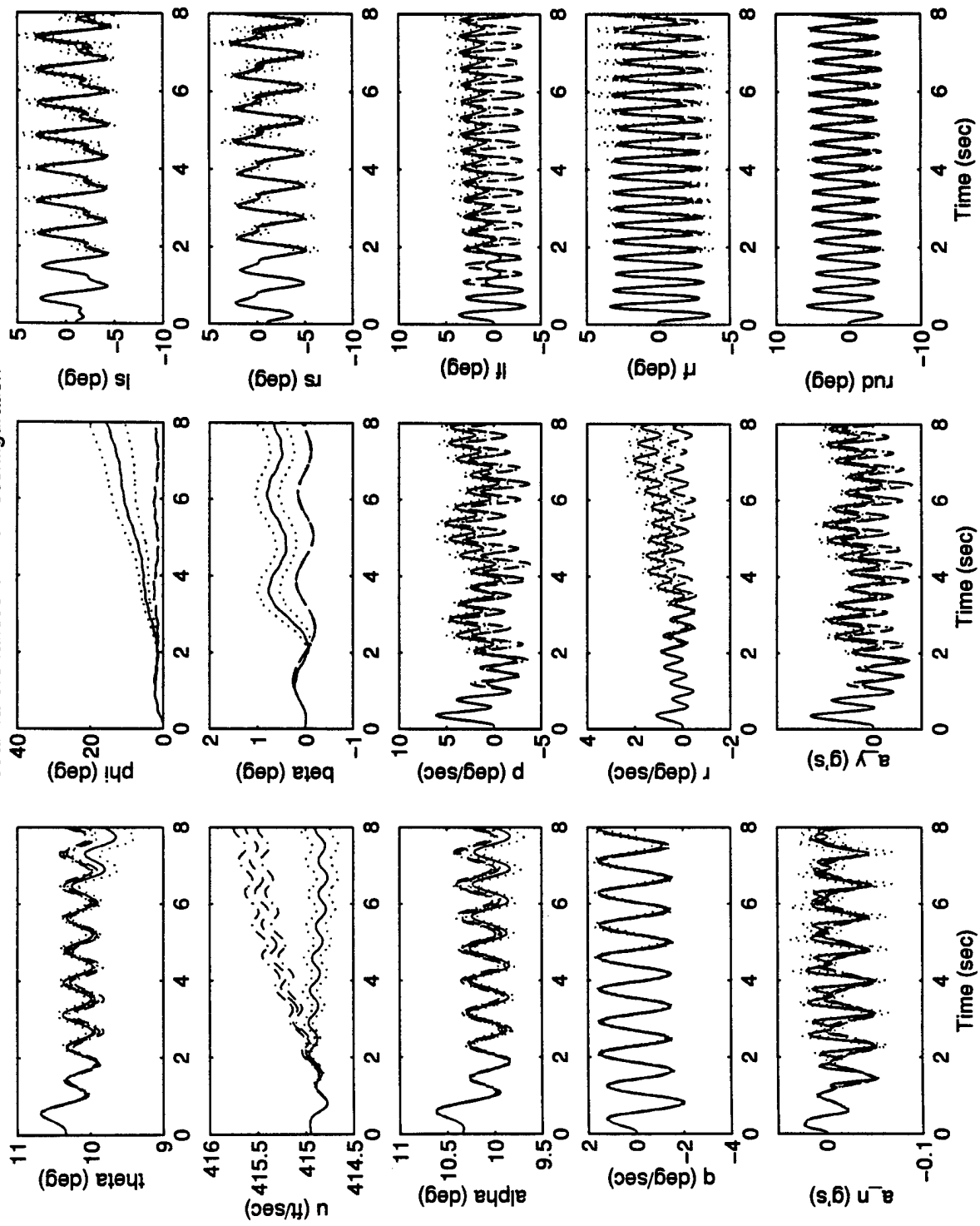dual-failure fail253.06 with reconfiguration
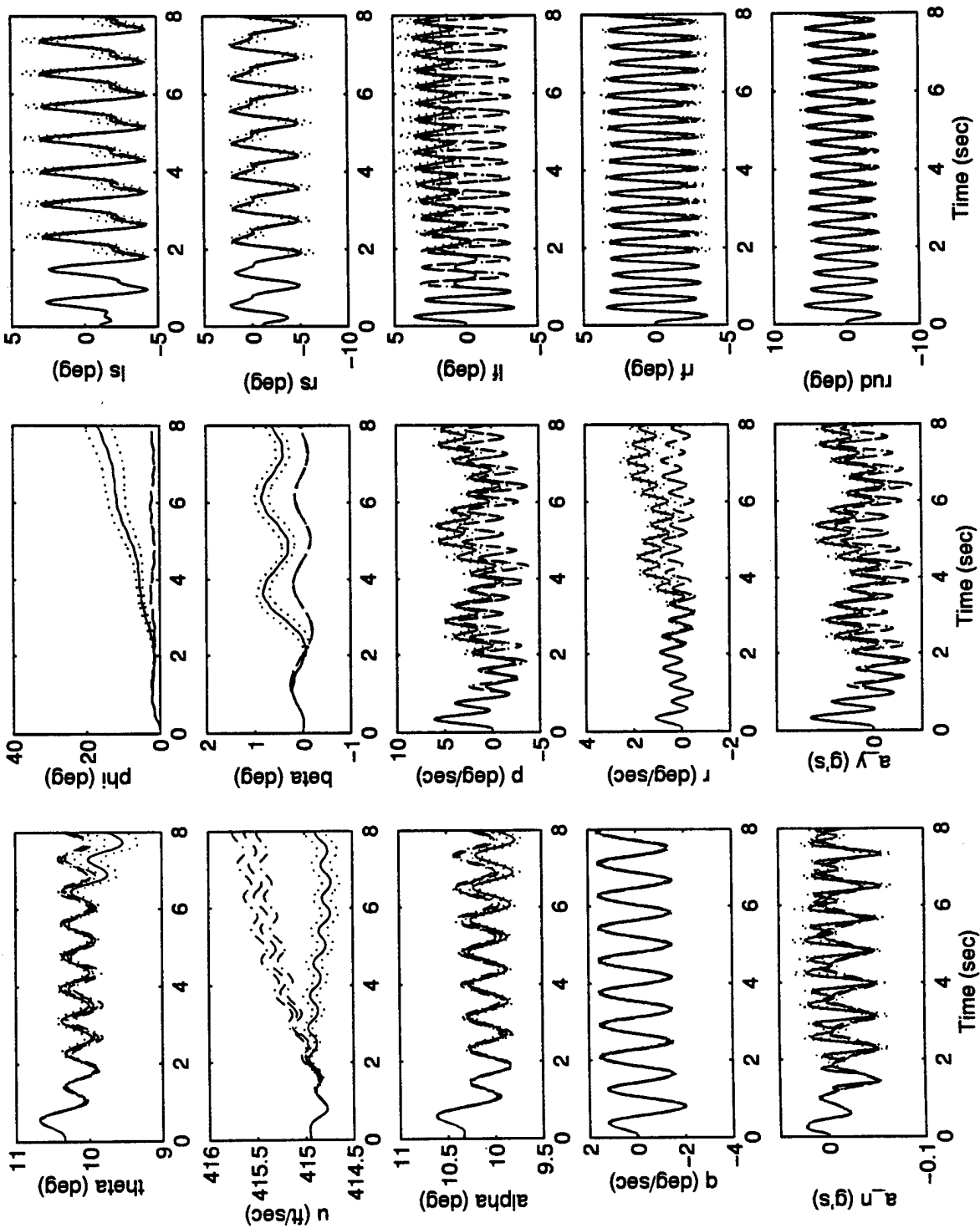
dual-failure fail253.07 with reconfiguration
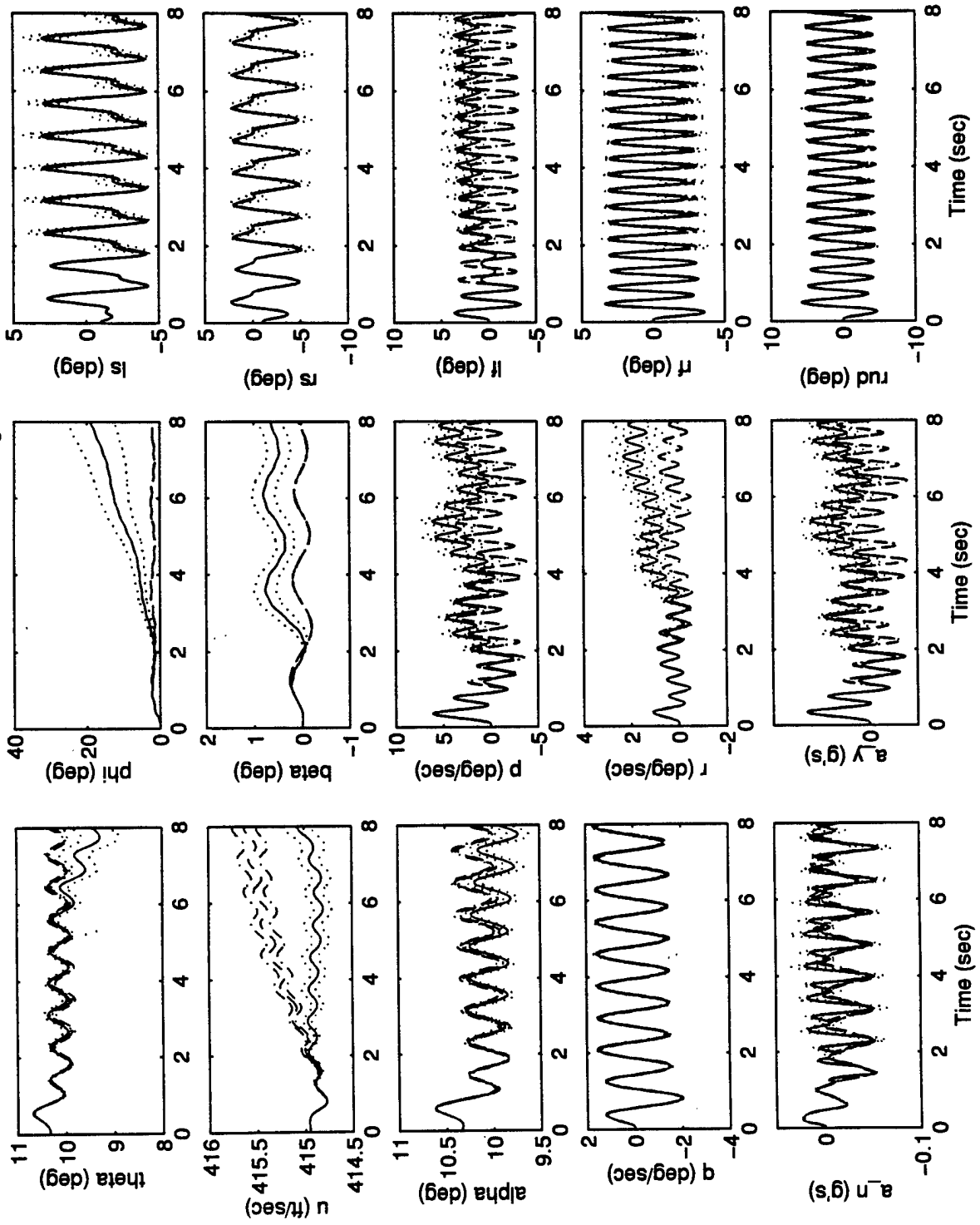
dual-failure fail253.08 with reconfiguration
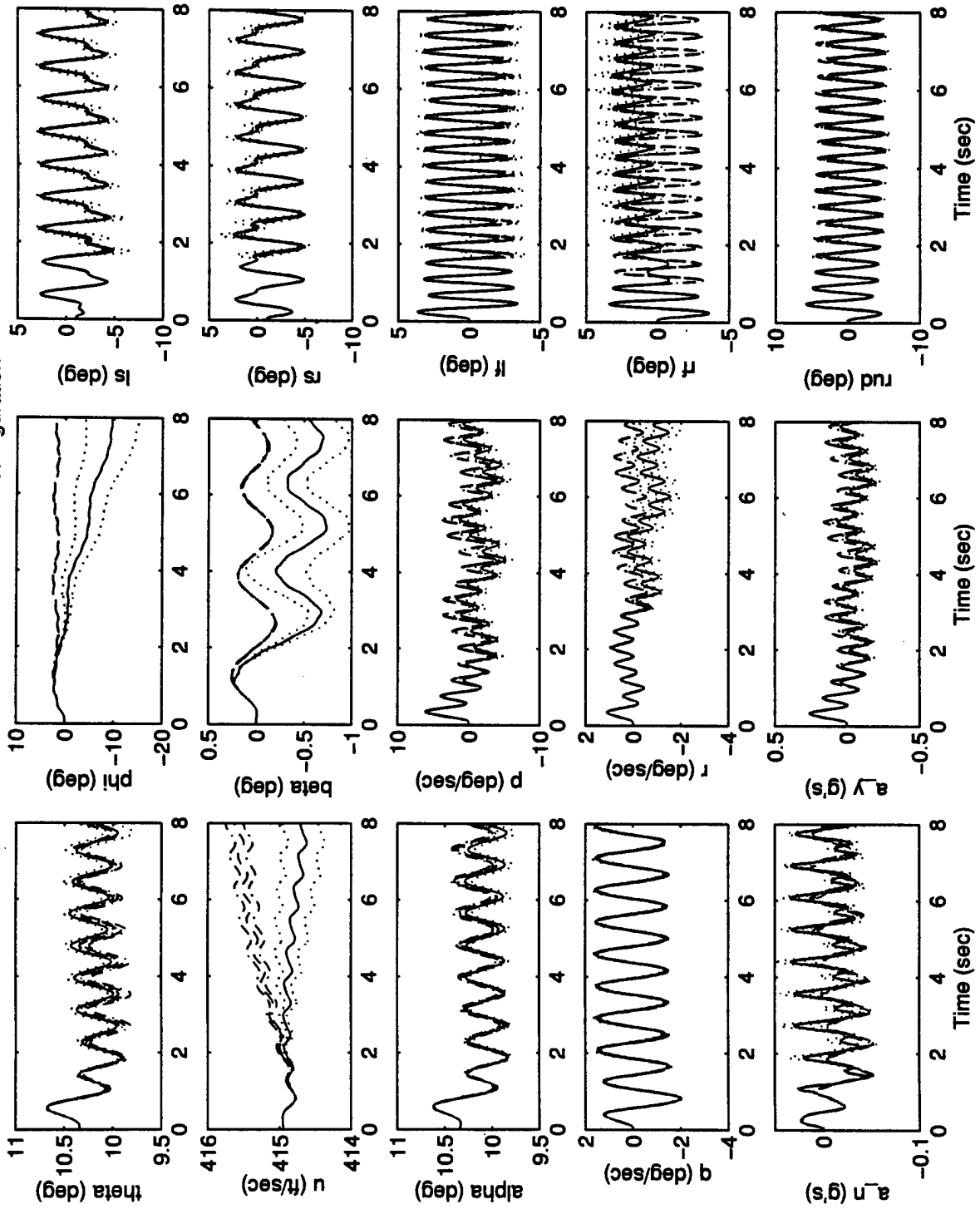
dual-failure fail253.09 with reconfiguration

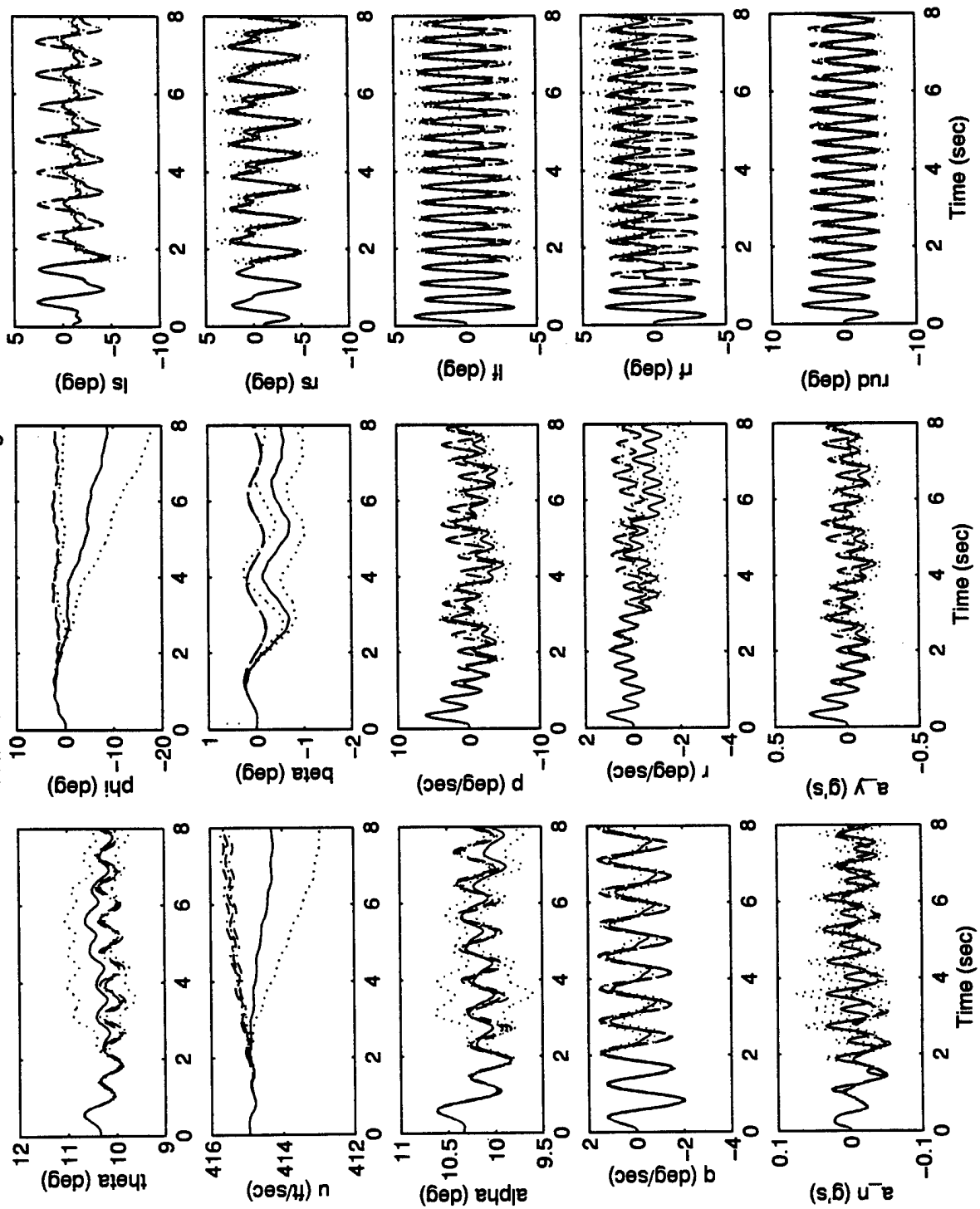dual-failure fail253.010 with reconfiguration

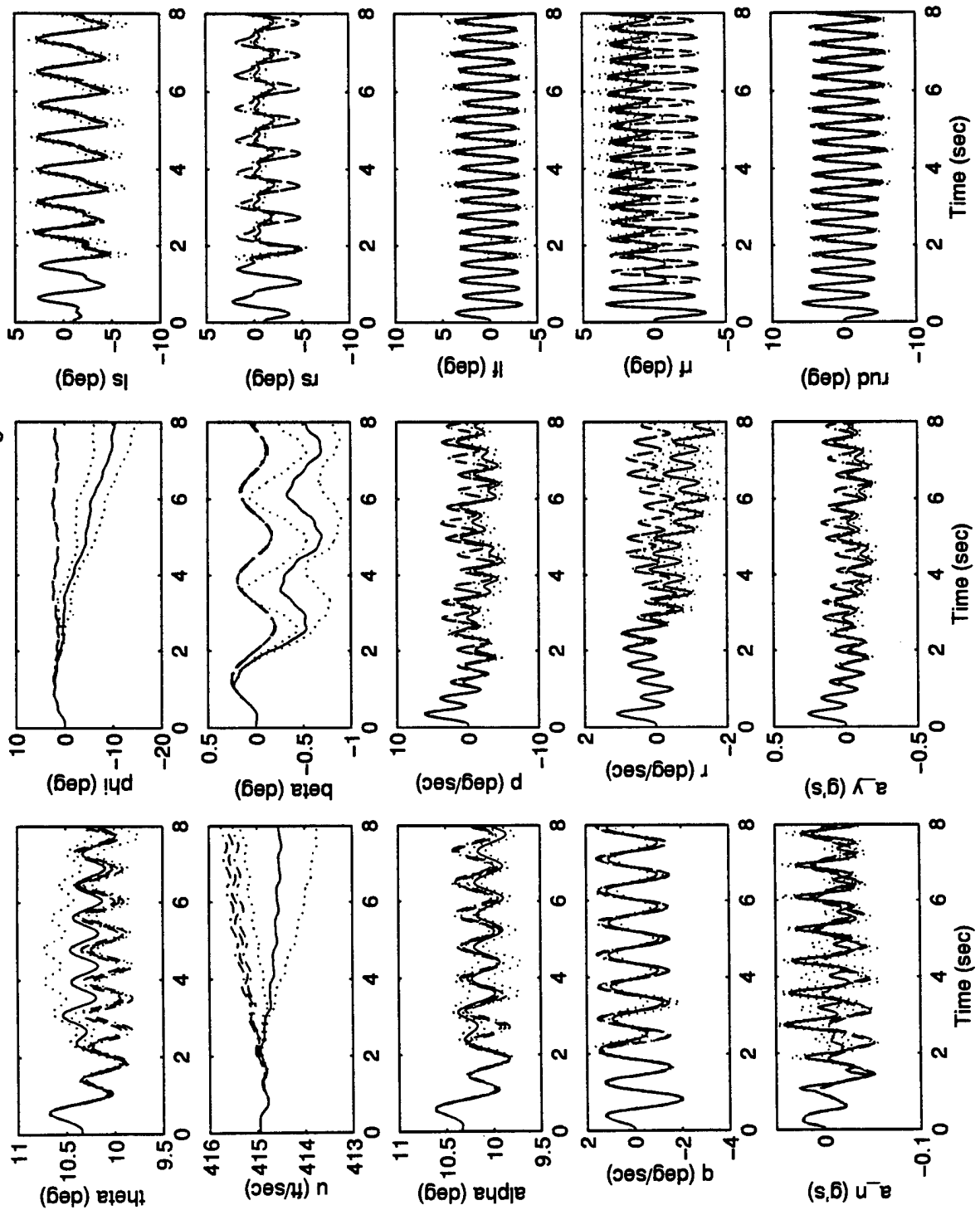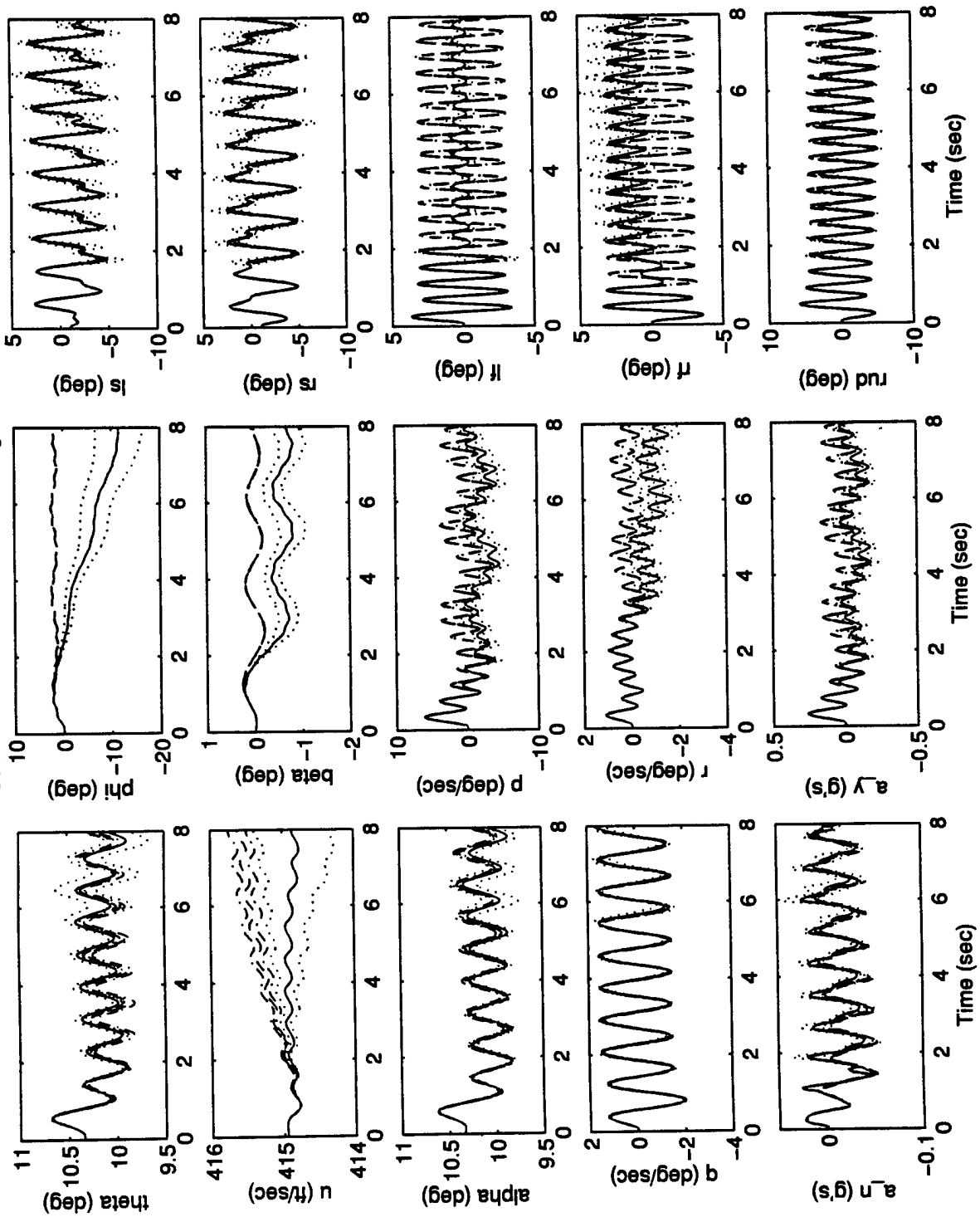dual-failure fail253.011 with reconfiguration
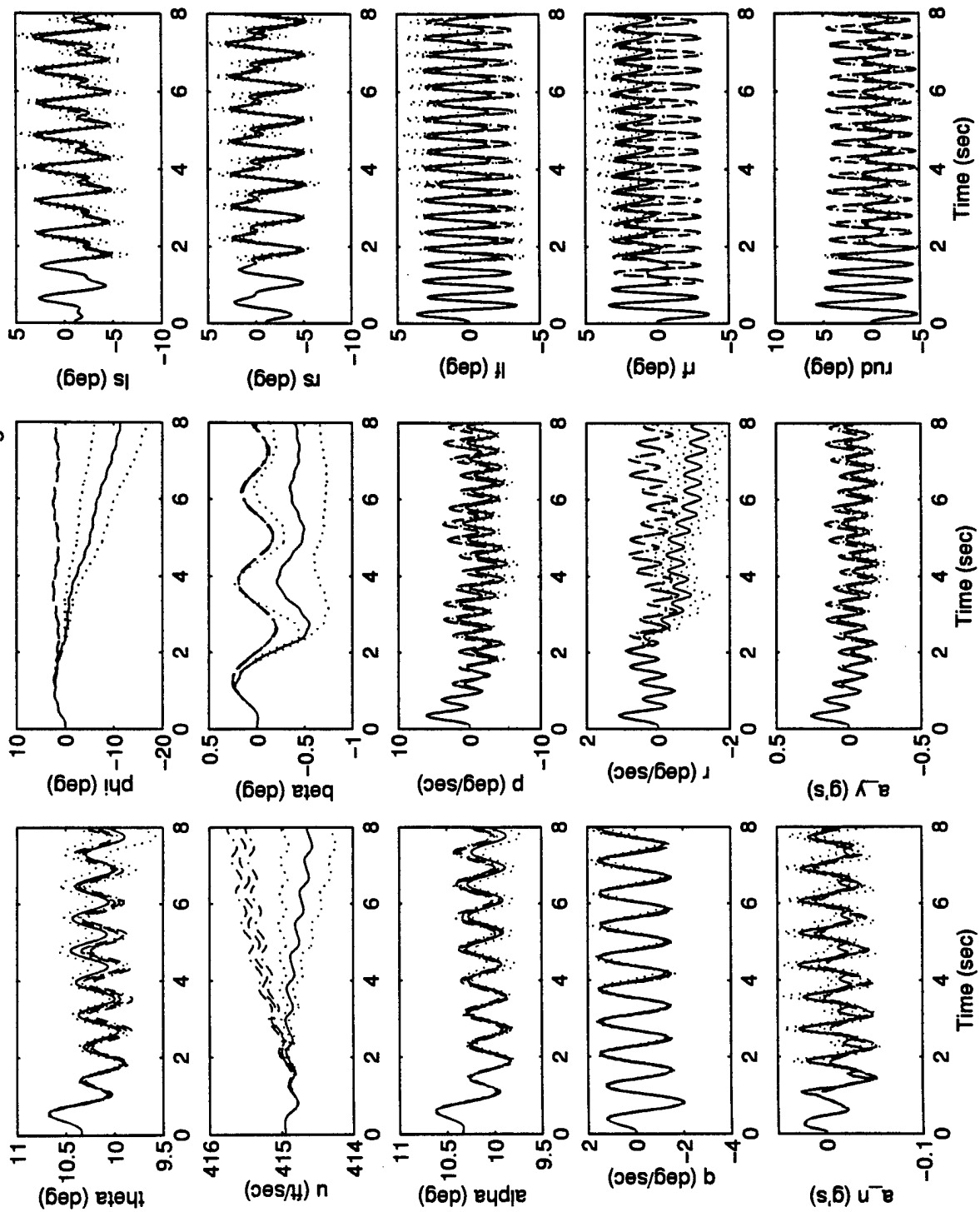
dual-failure fail254.250 with reconfiguration

dual-failure fail254.251 with reconfiguration

dual-failure fail254.252 with reconfiguration

ls (deg) · rs (deg) · lf (deg) · rf (deg) · rud (deg)

phi (deg) · beta (deg) · p (deg/sec) · r (deg/sec) · a_y (g's)

theta (deg) · u (ft/sec) · alpha (deg) · q (deg/sec) · a_n (g's)
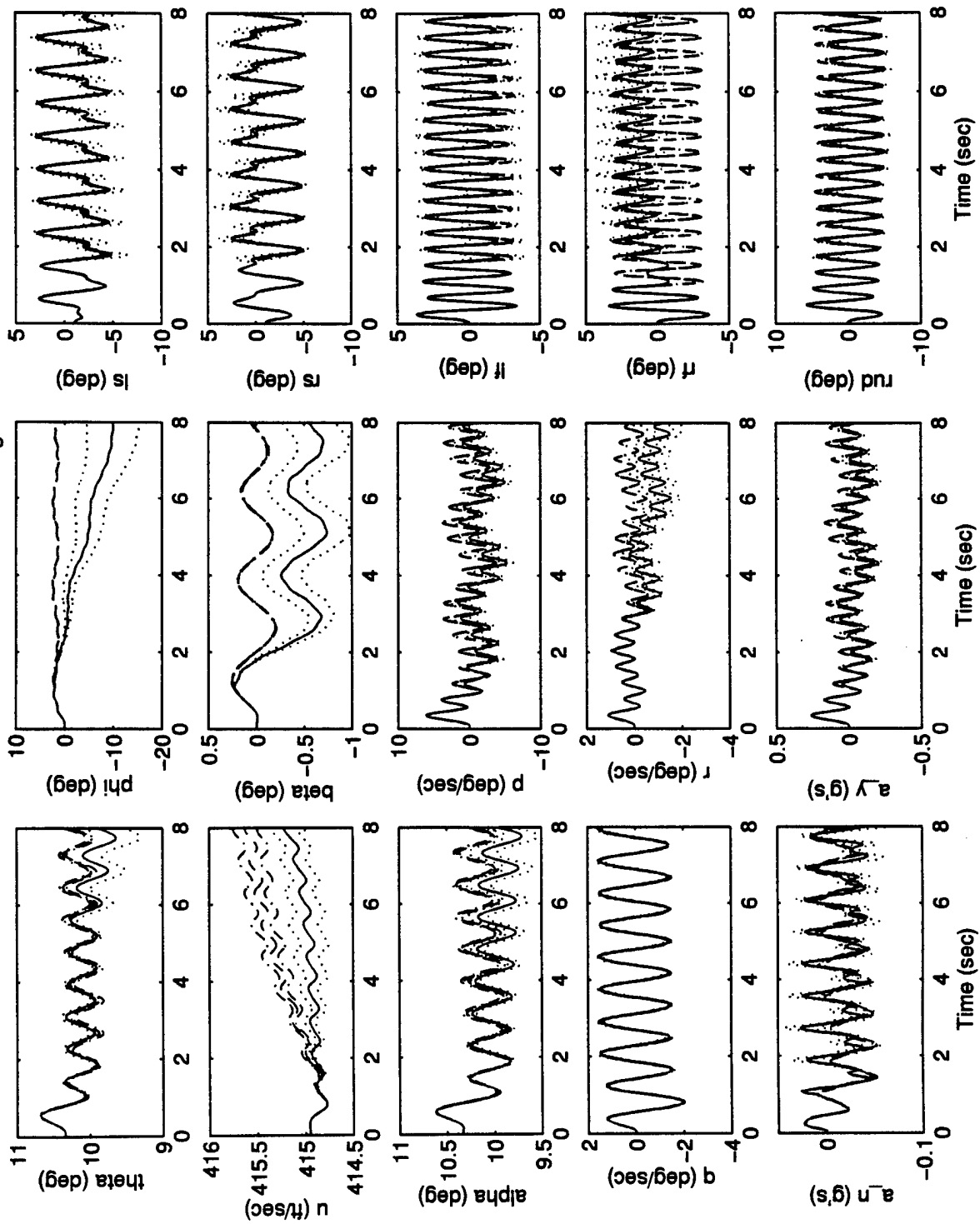
Time (sec)

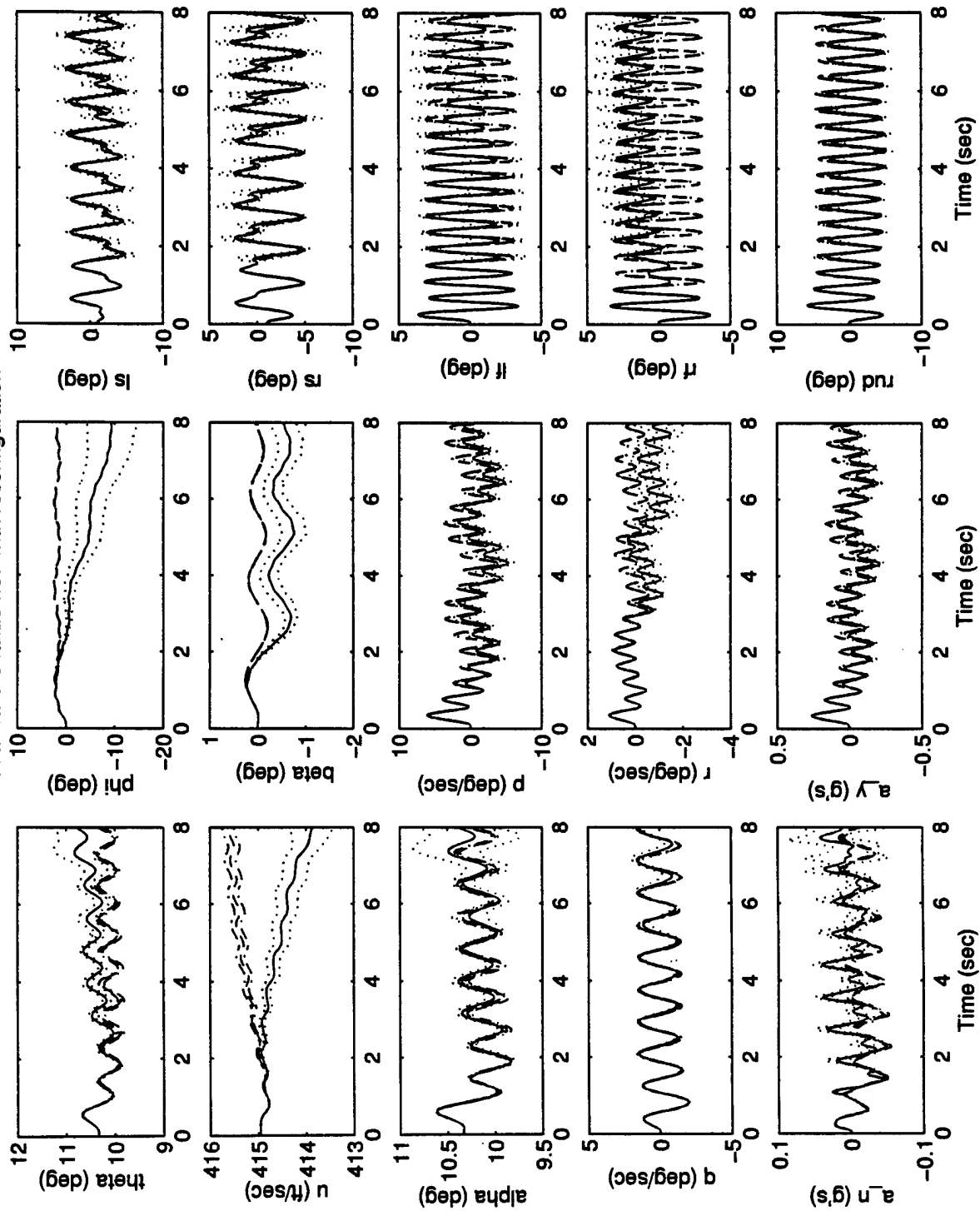dual-failure fail254.253 with reconfiguration

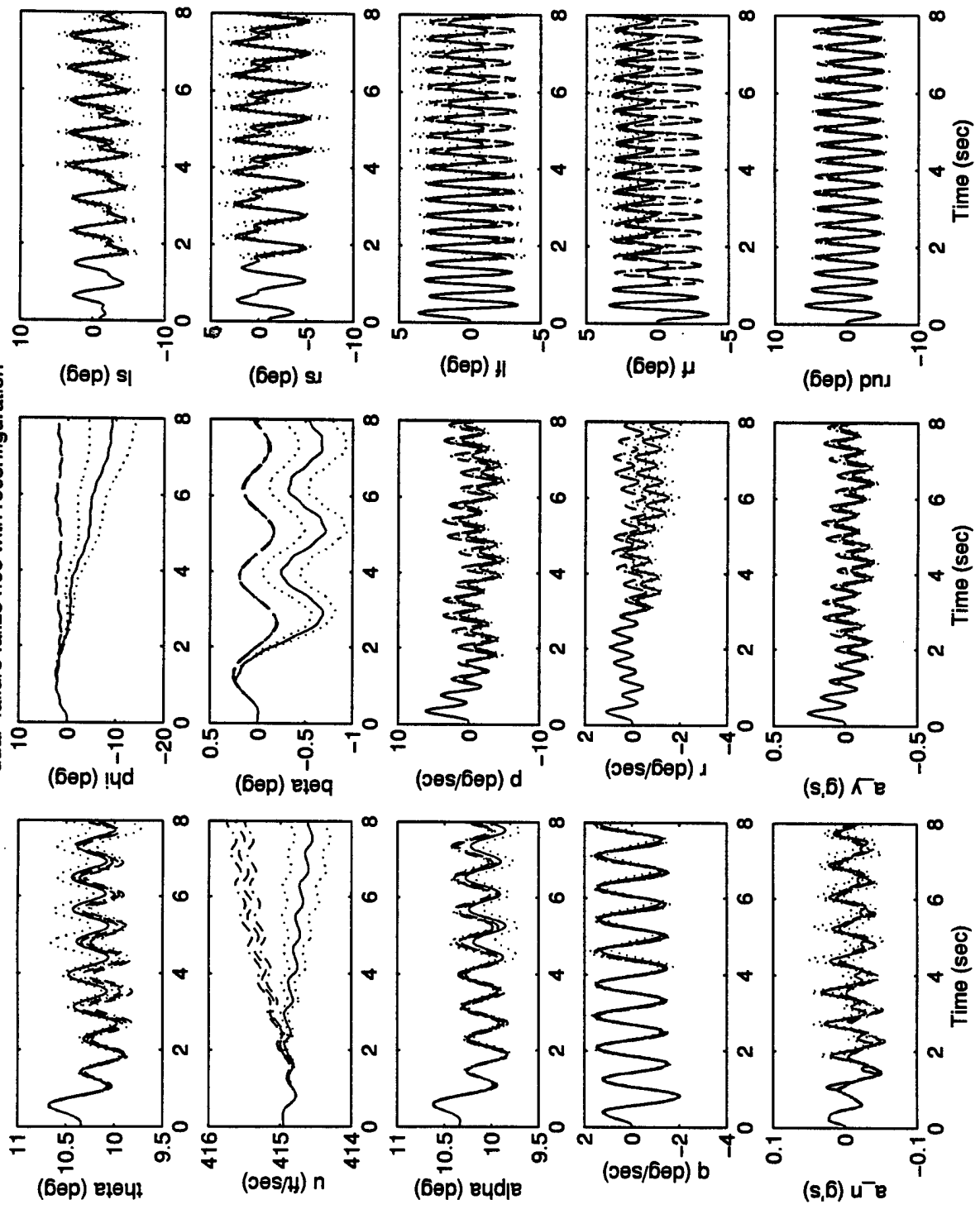dual-failure fail254.255 with reconfiguration
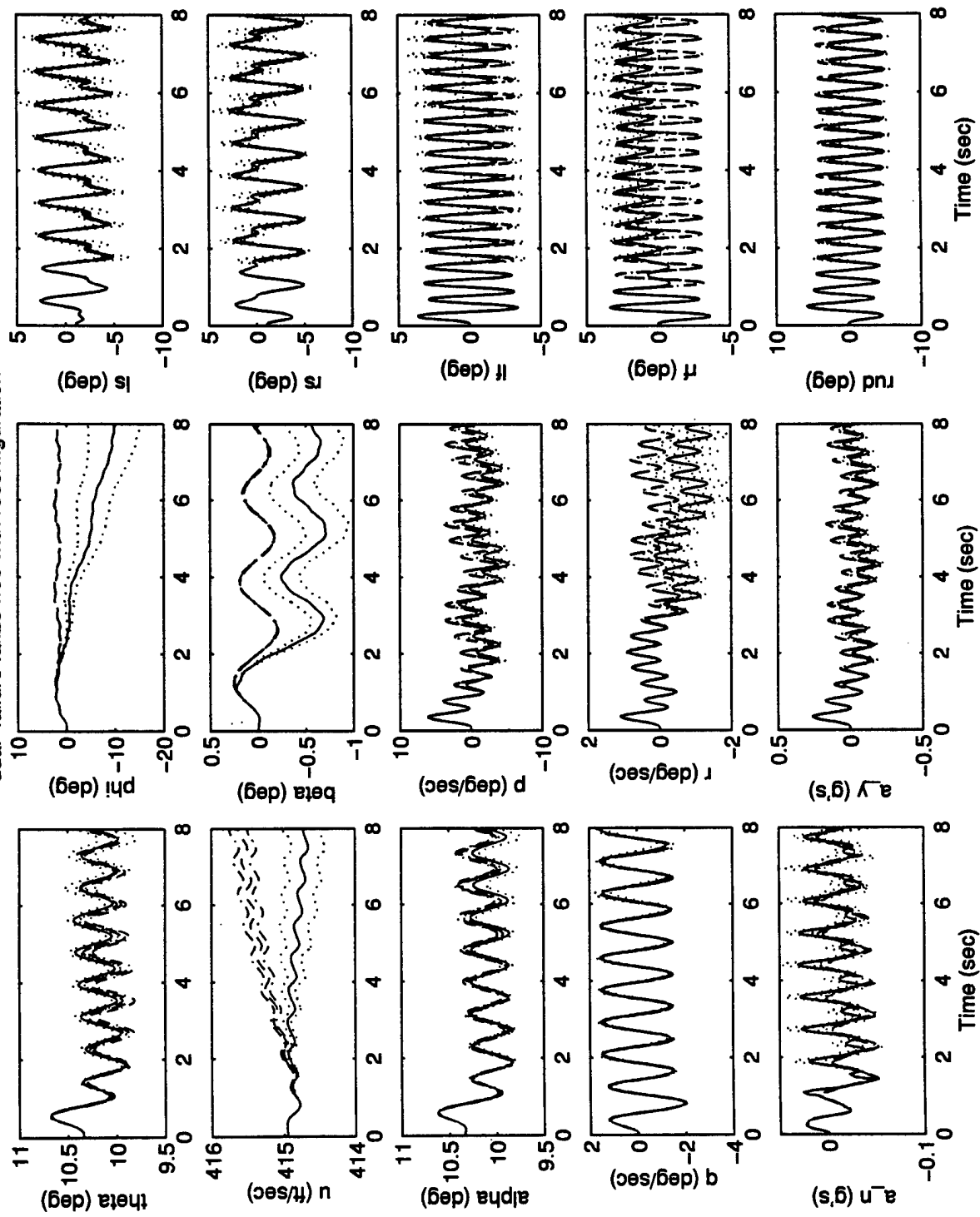
dual-failure fail254.06 with reconfiguration

dual-failure fail254.07 with reconfiguration

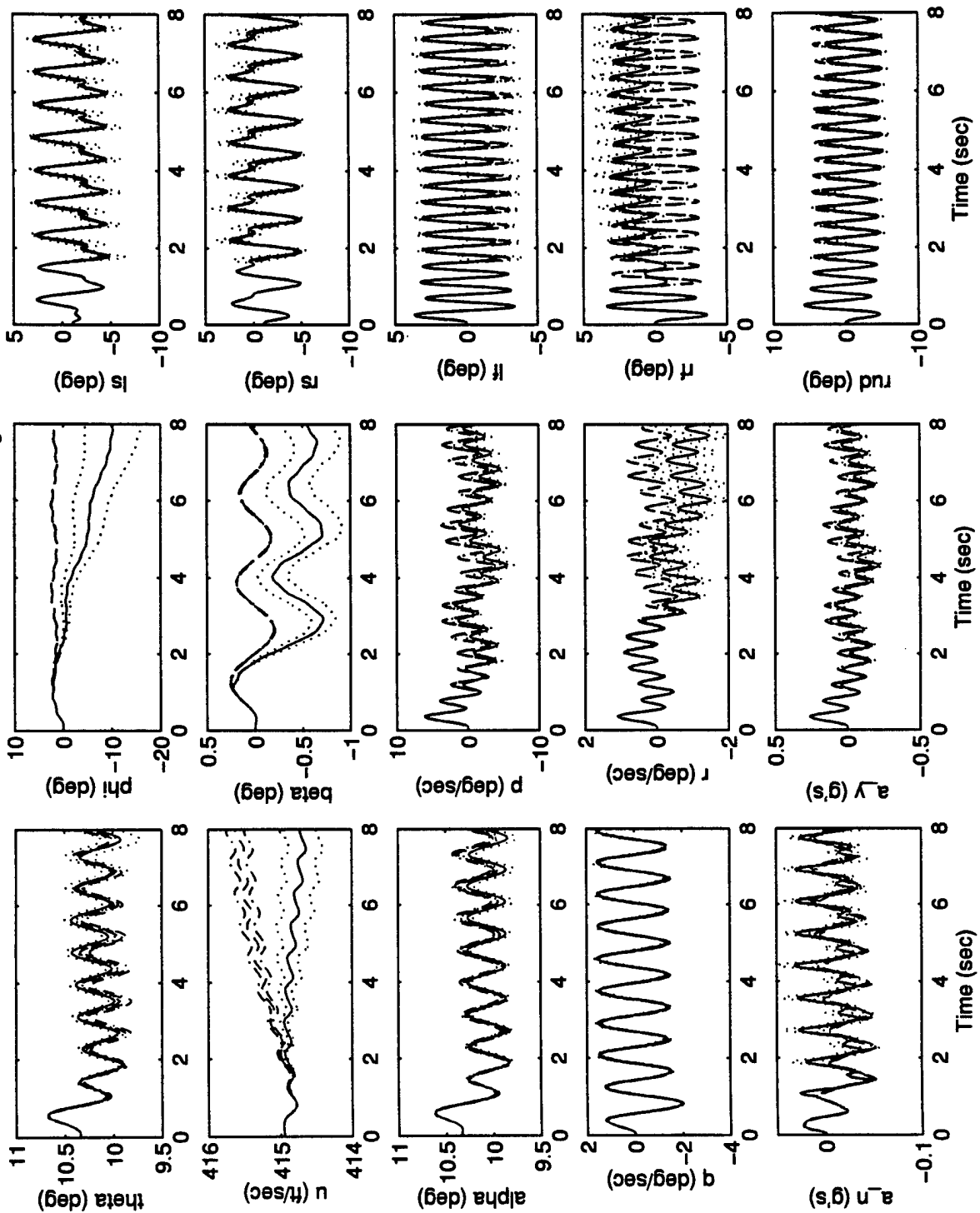dual-failure fail254.08 with reconfiguration

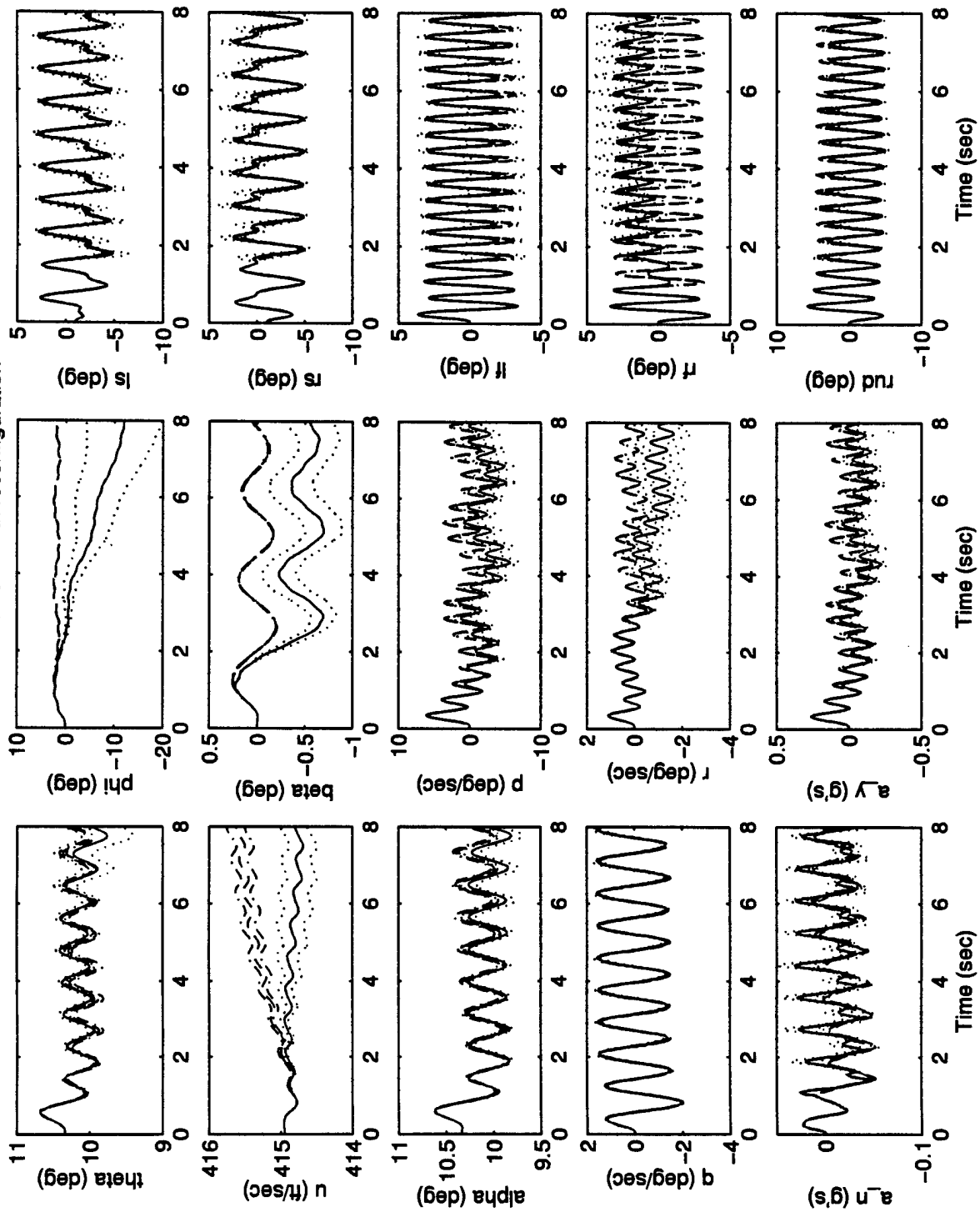dual-failure fail254.09 with reconfiguration

dual-failure fail254.010 with reconfiguration

dual-failure fail254.011 with reconfiguration

dual-failure fail255.250 with reconfiguration

dual-failure fail255.251 with reconfiguration

dual–failure fail255.252 with reconfiguration

dual-failure fail255.253 with reconfiguration

dual-failure fail255.254 with reconfiguration

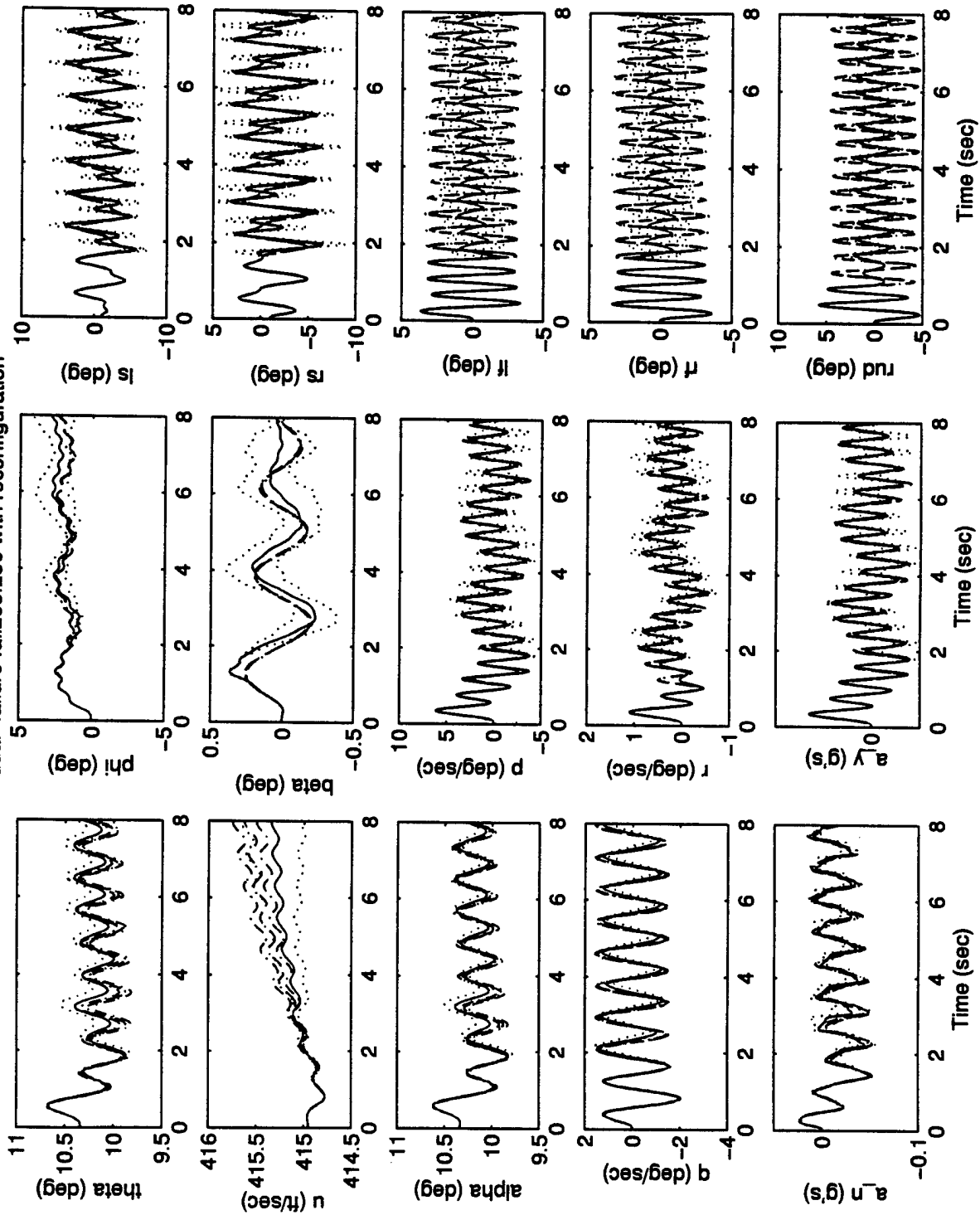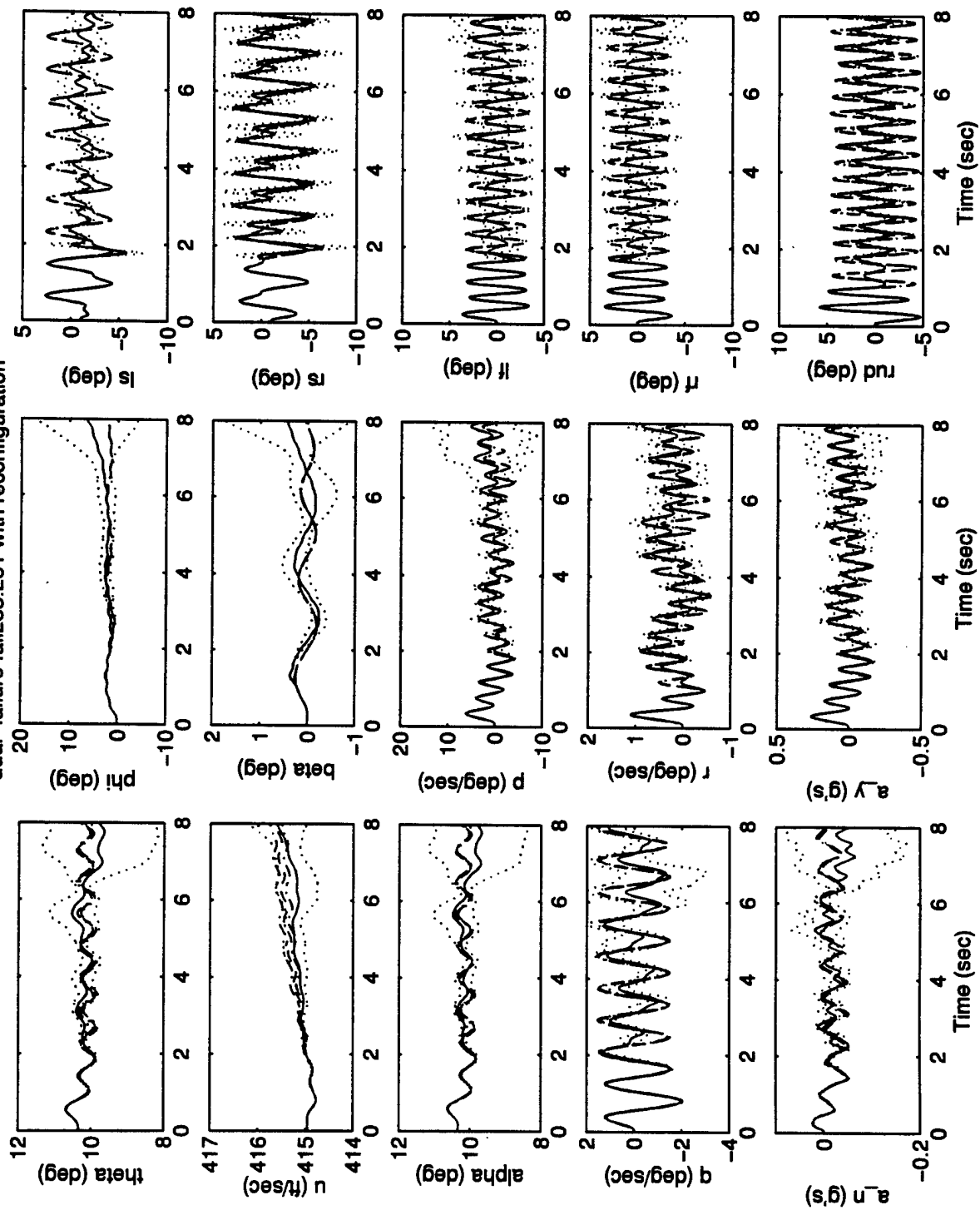dual-failure fail255.06 with reconfiguration

dual-failure fail255.07 with reconfiguration

dual-failure fail255.08 with reconfiguration

dual-failure fail255.09 with reconfiguration

dual–failure fail255.010 with reconfiguration
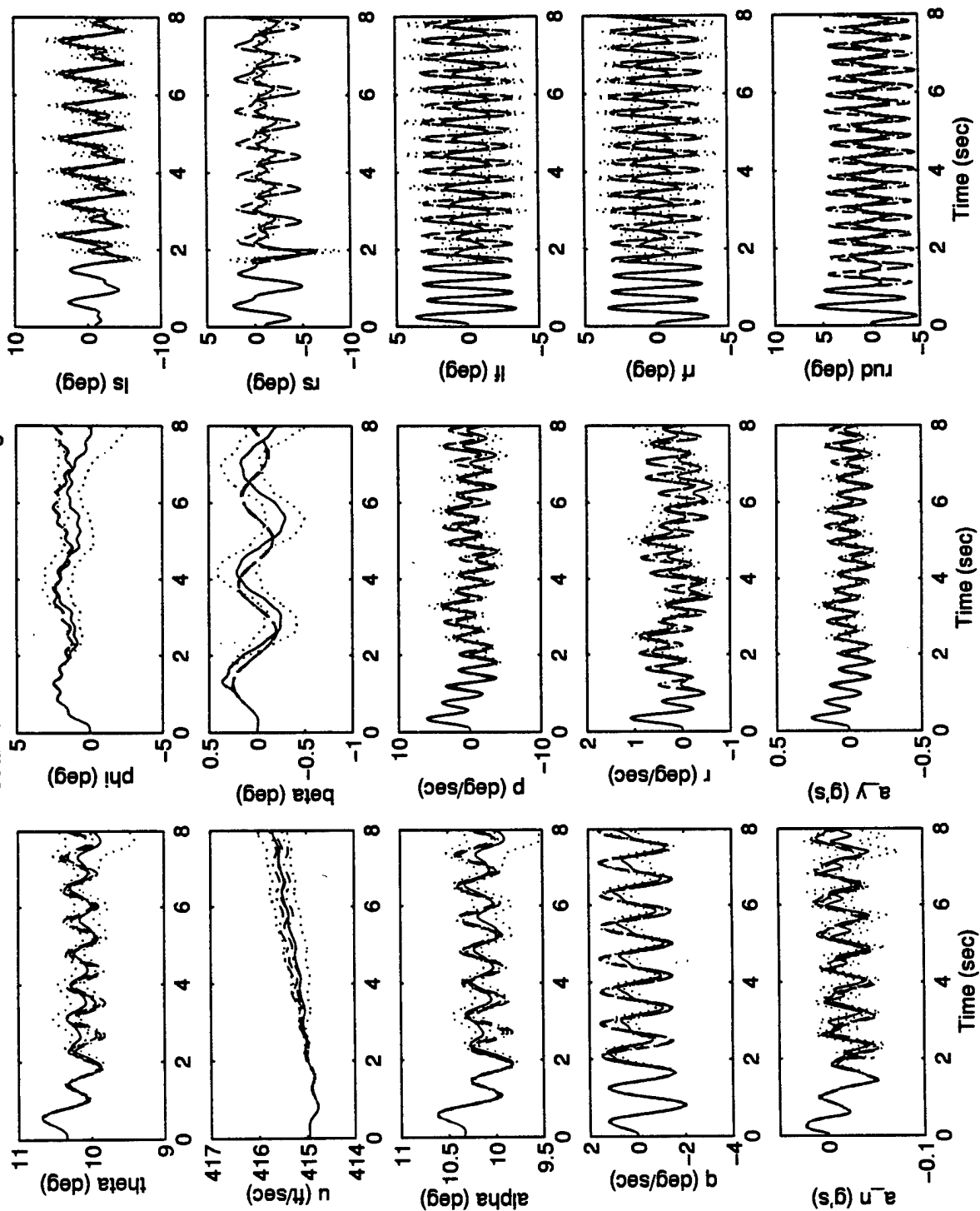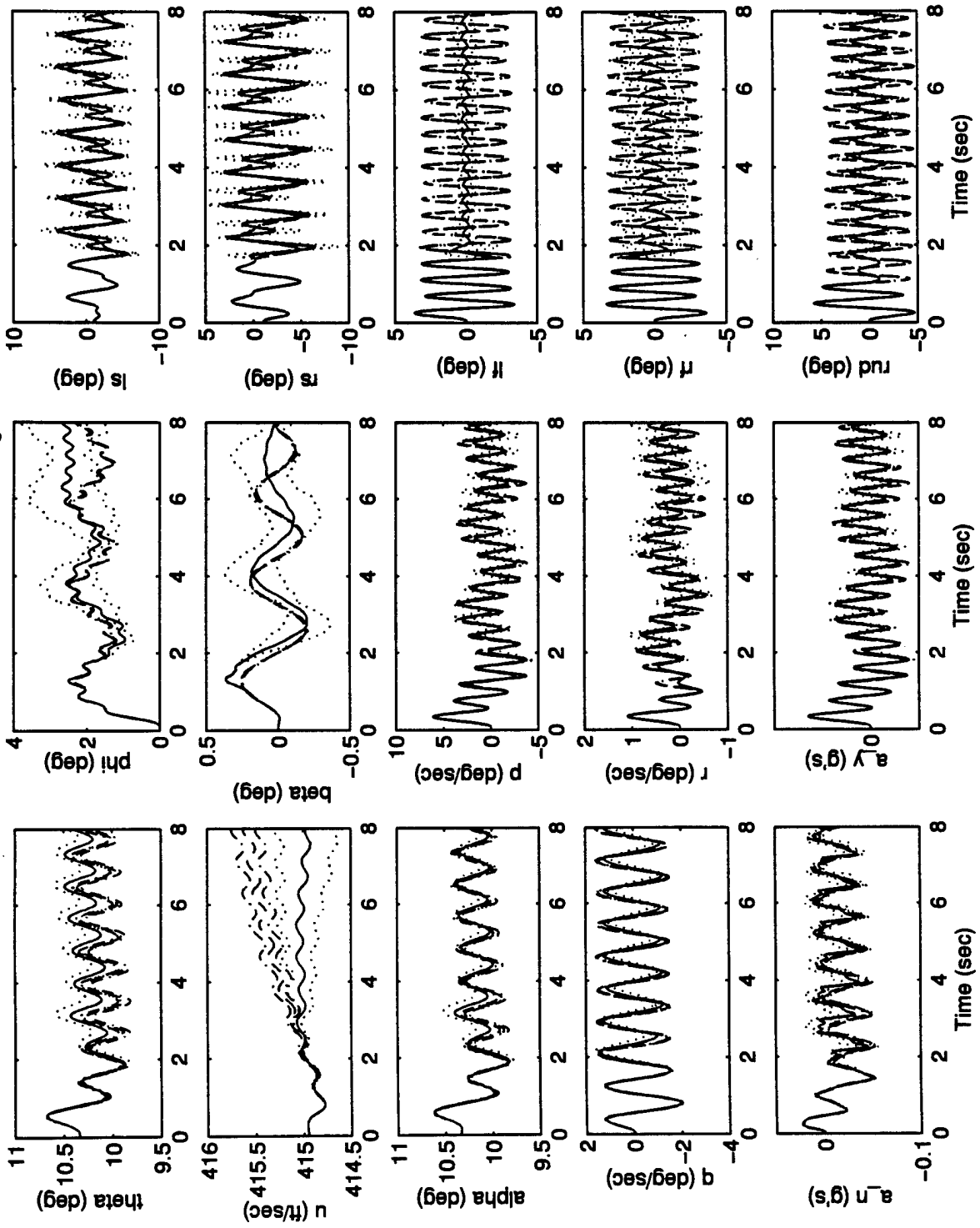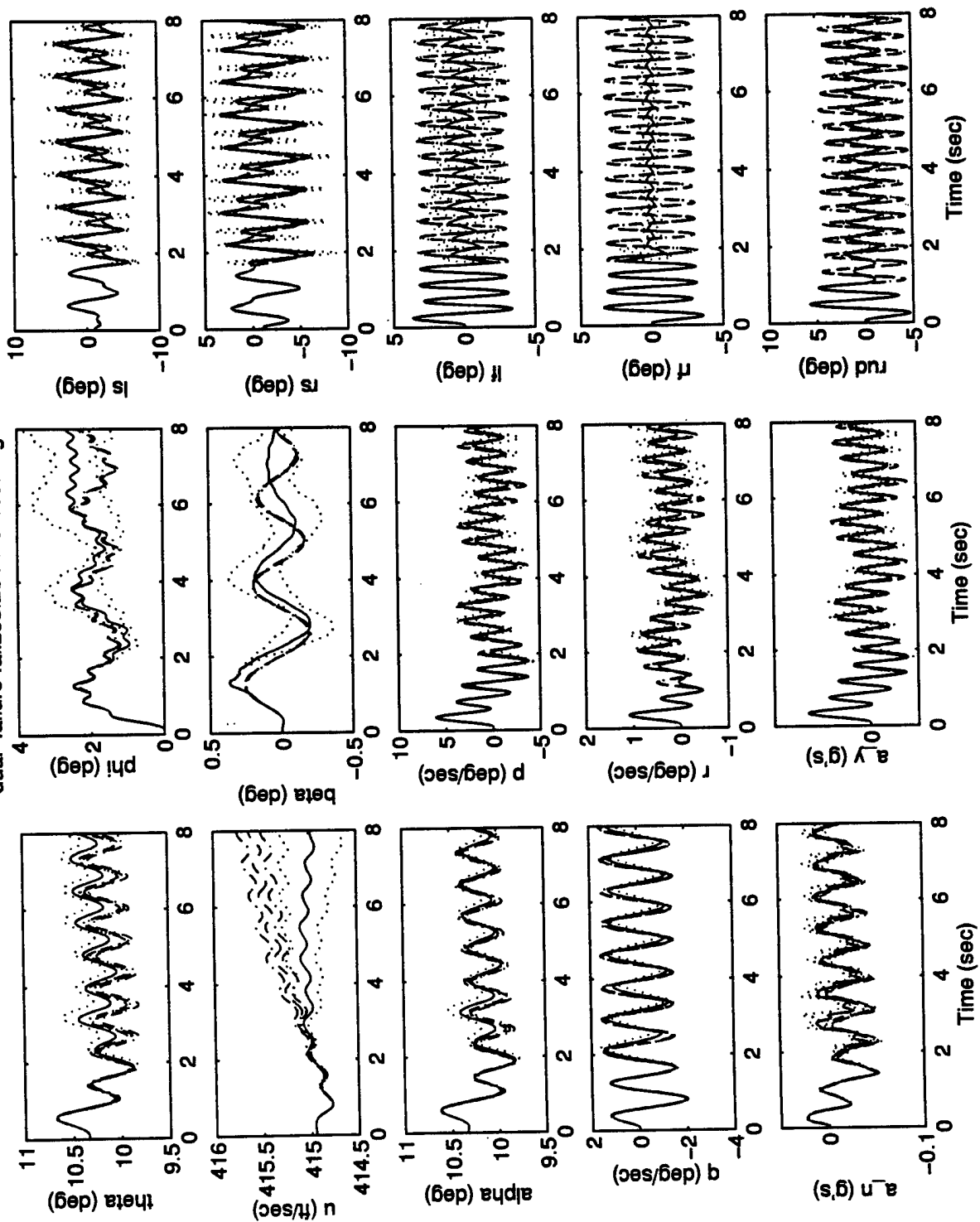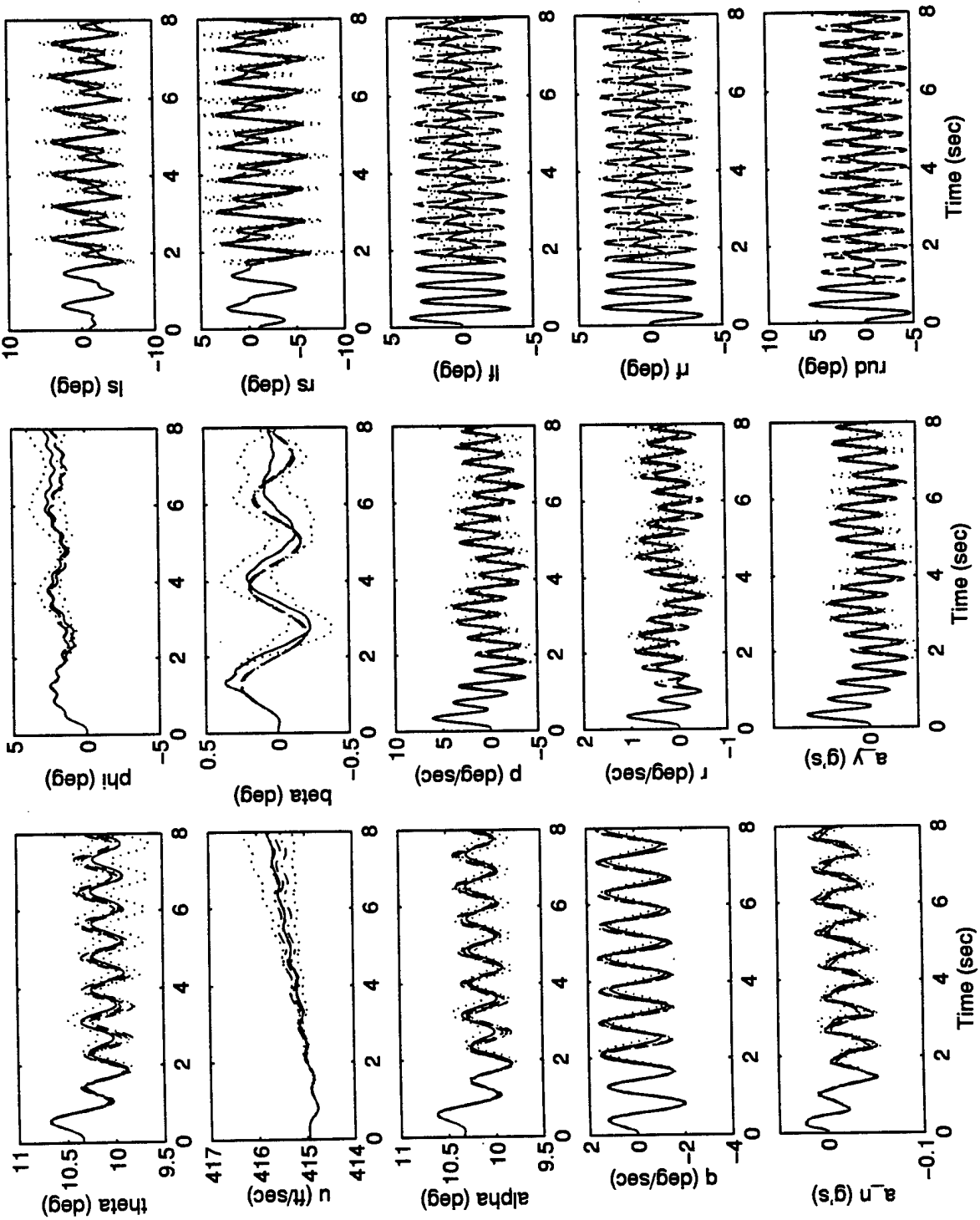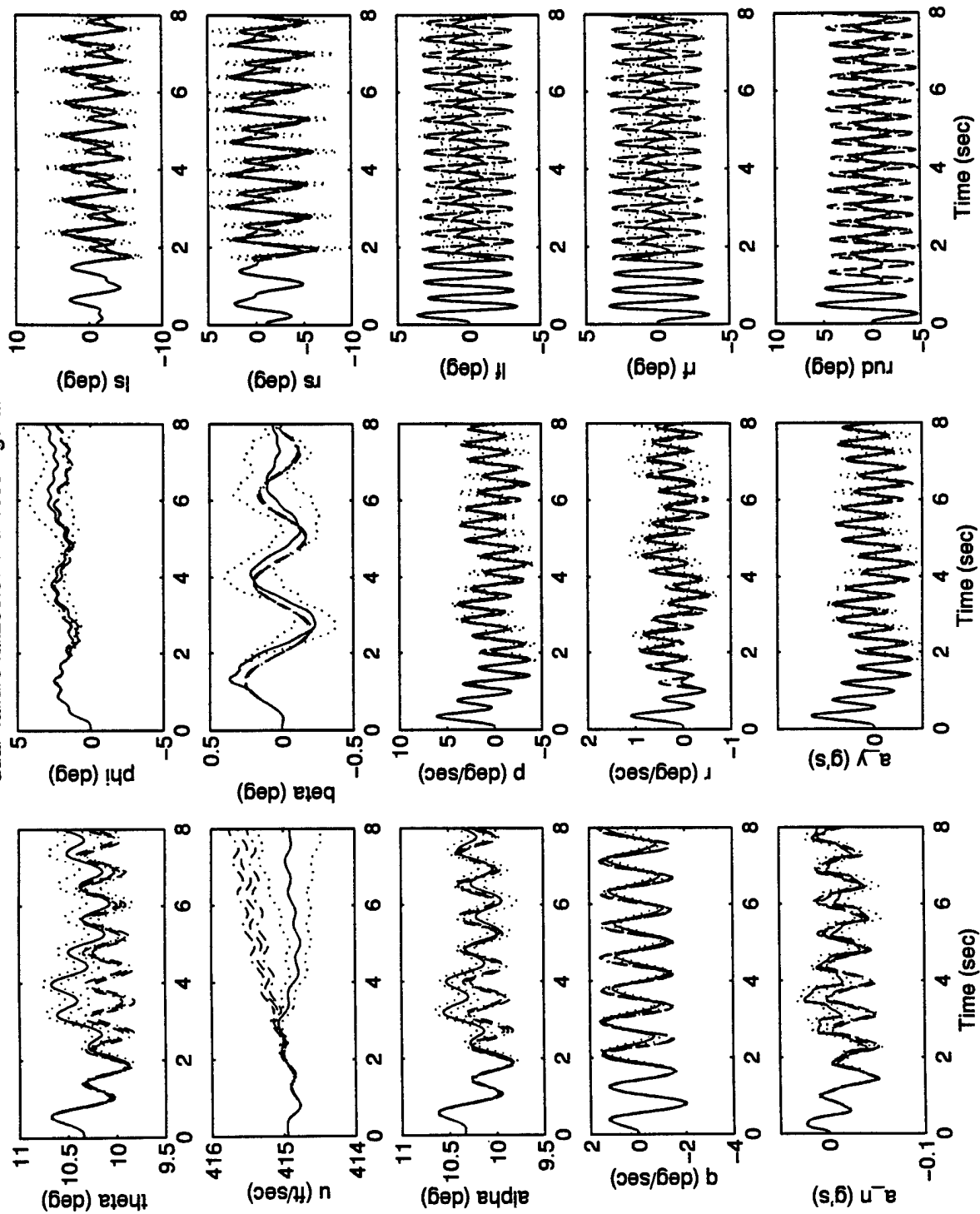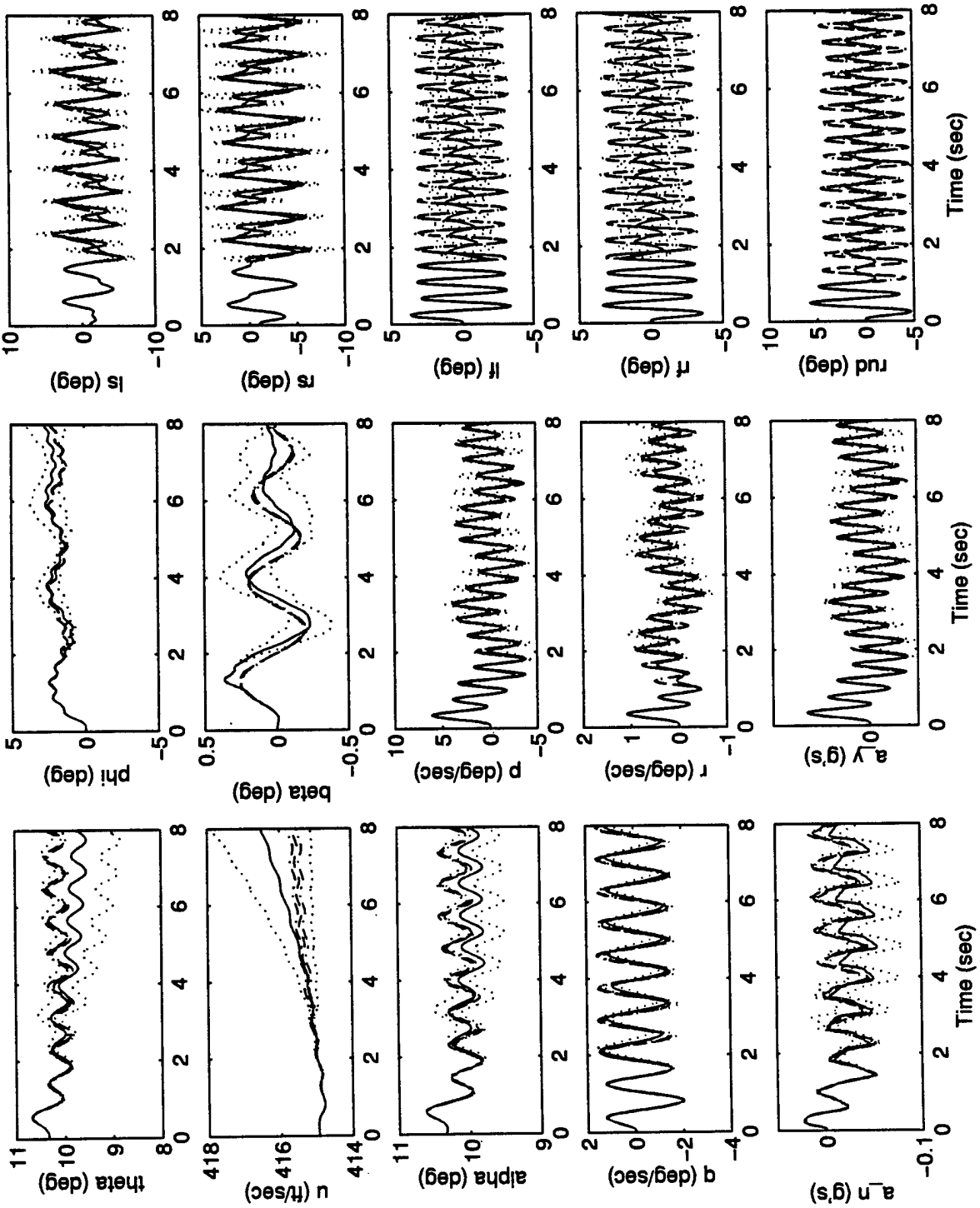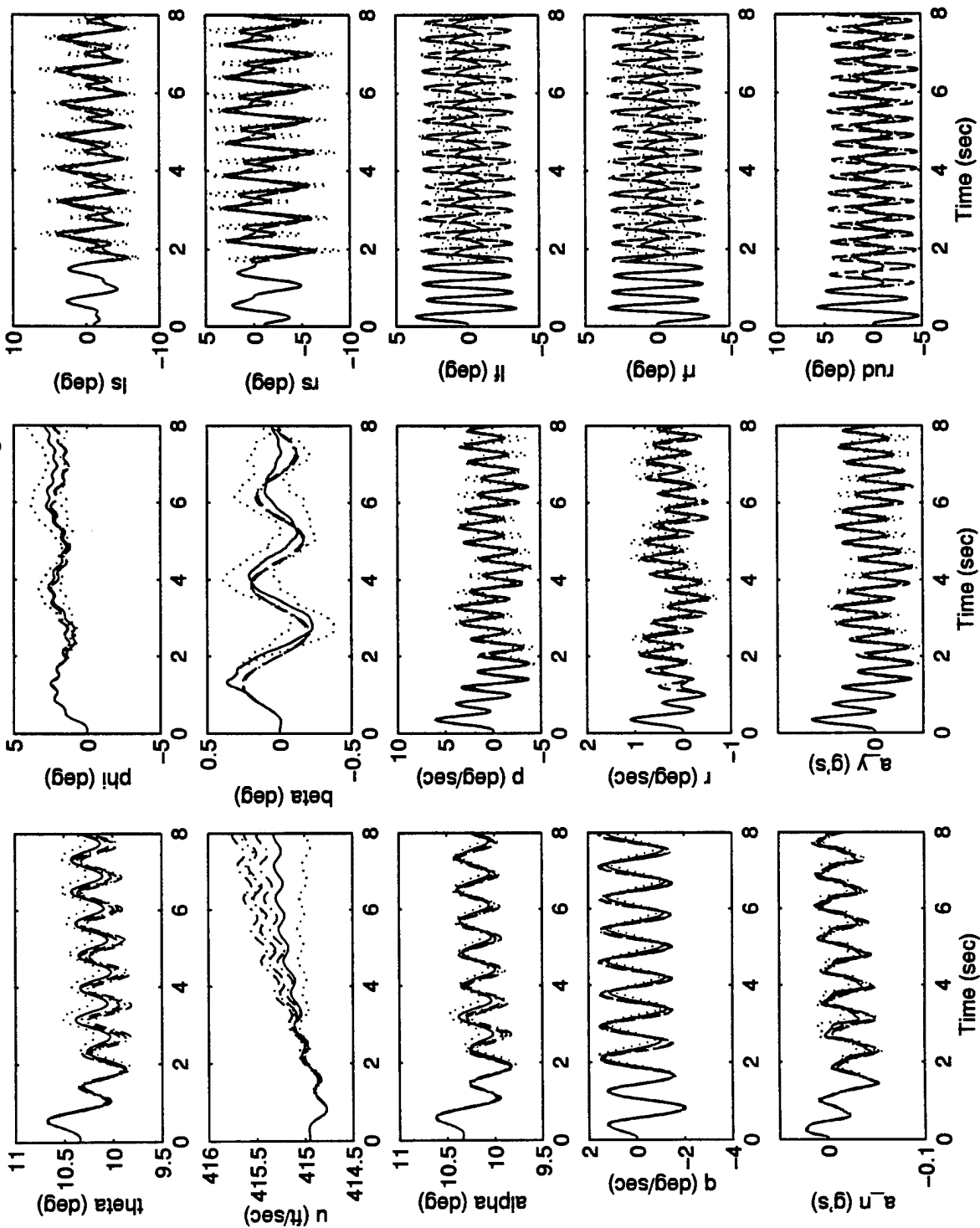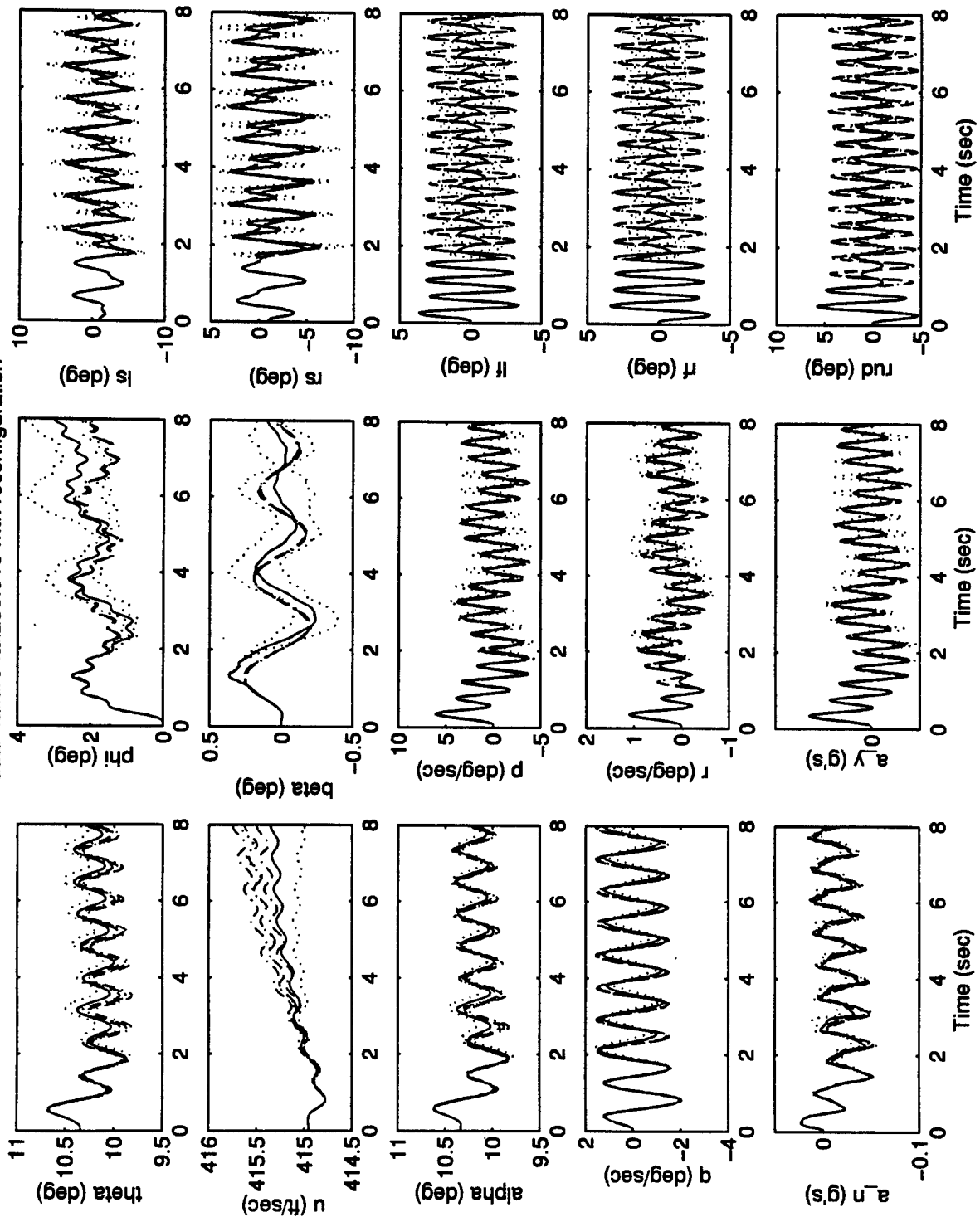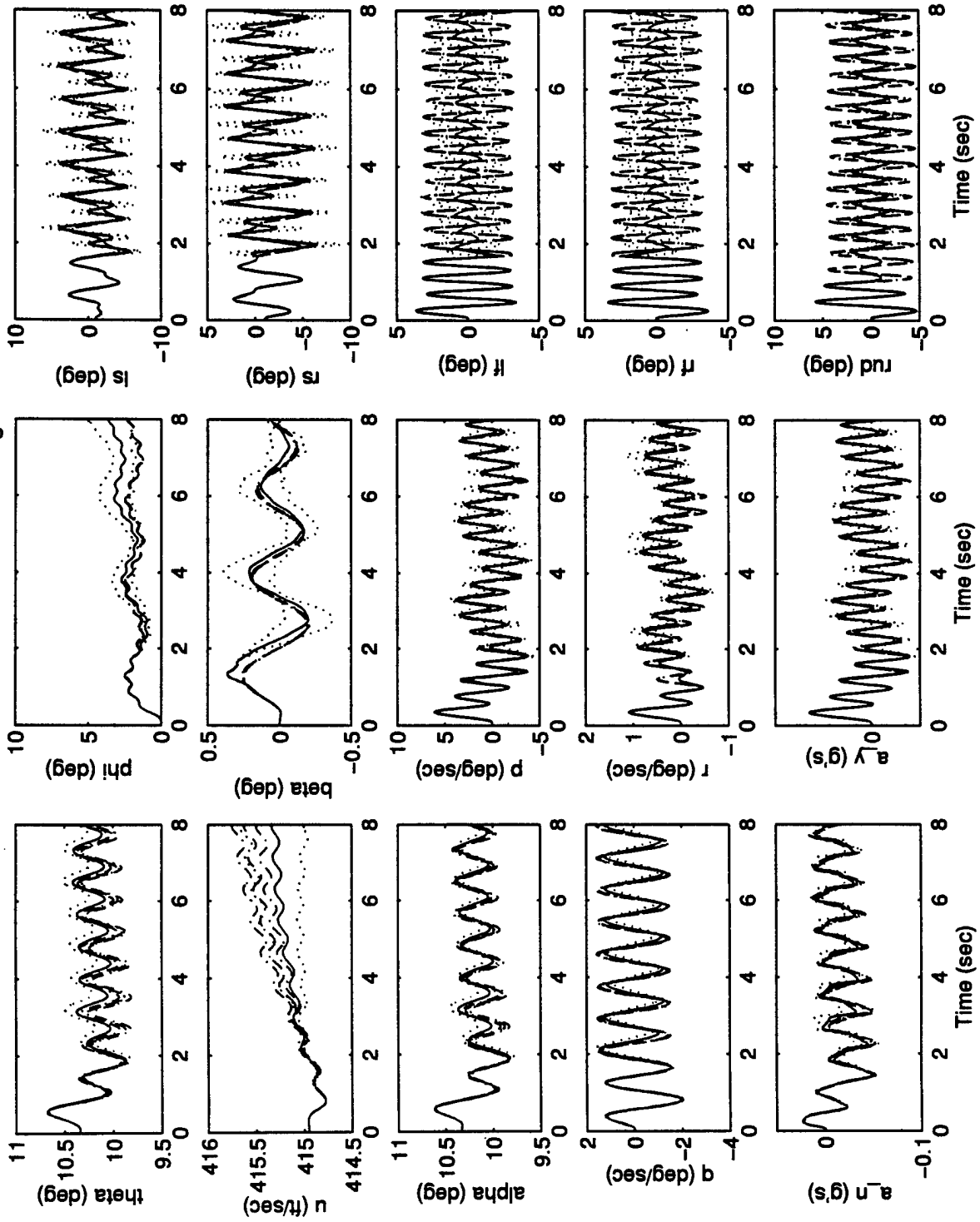
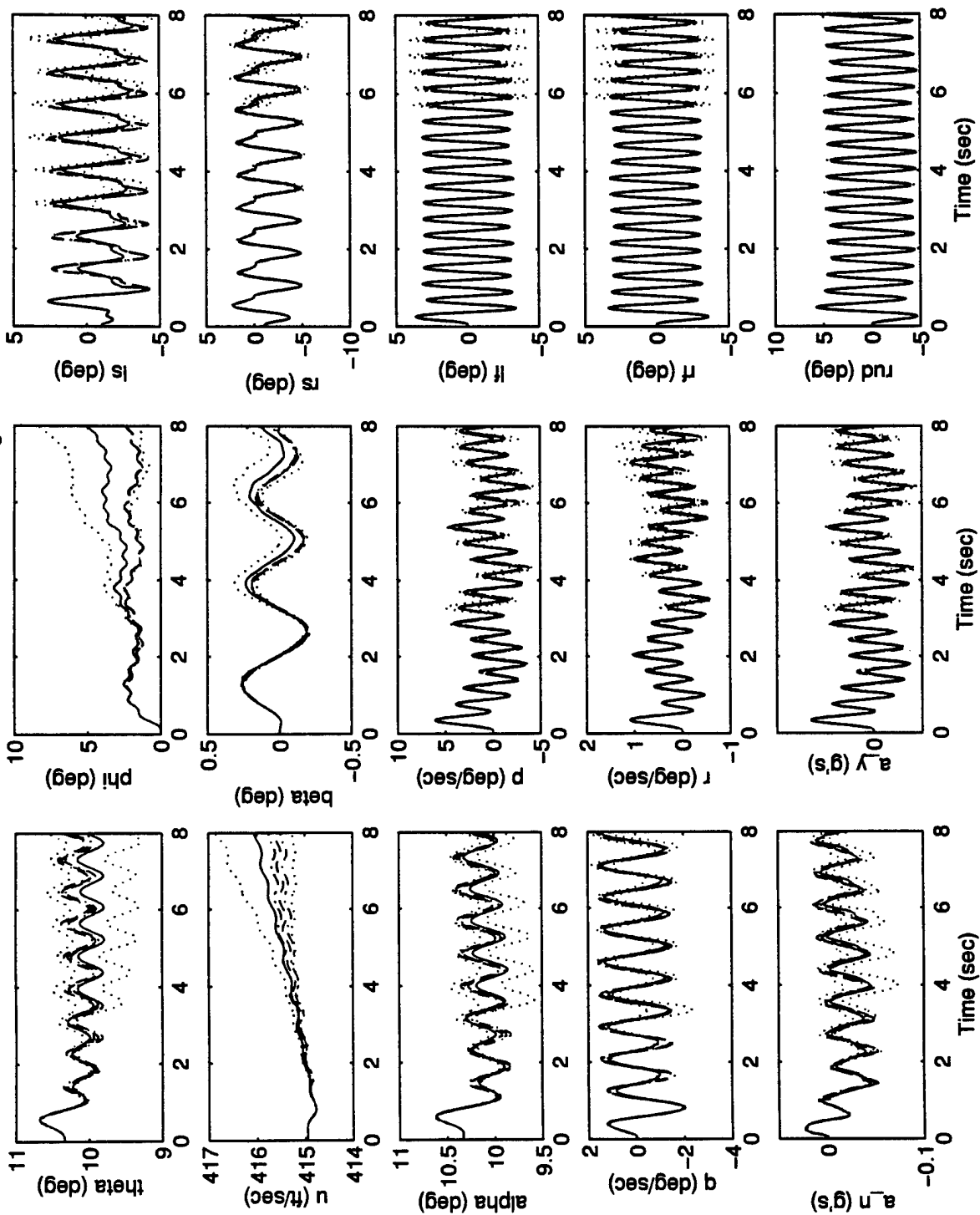dual-failure fail255.011 with reconfiguration

This appendix contains the state plots for "50% actuator / 50% actuator" and "50% actuator / total sensor" dual impairment scenarios, *with* Control Reconfiguration (Redistribution) and with control dithering (Section 4.13.3 and Appendix D.3). The first impairment is inserted at 1 second, followed by the second impairment at 2 seconds, and in all cases, there is no aircraft maneuvering. Table H.3 on the following page lists the impairment cases, by case number, which are to be found in this appendix. The leftmost column of Table H.3 represents the first impairment occurring at 1 second, while the top row represents the second impairment occurring at 2 seconds. The table entries list the failure codes found in the plot titles for the failure case represented by the table row and column. **Bold** entries correspond to cases of no second impairment. As an example, the entry for a left stabilator (LS) impairment at 1 second, followed by a right flaperon (RF) impairment at 2 seconds is found in entry '(LS, RF)' in the table, and the corresponding failure case is 'fail501.504'. The state plot will contain this code ('fail501.504') in the plot title. In fact, for this specific case, the plot title is: "dual-failure fail501.504 with reconfiguration". Each page of State Plots in this appendix contains three columns of five plots and corresponds to one impairment condition, or test point. The first column shows the aircraft longitudinal states and normal acceleration (a_n). Column two shows lateral-directional states and lateral acceleration (a_y). The third column, of most interest to us, displays actuator positions (not commands). Two actual time histories, the result of a 10-run Monte Carlo simulation of each impairment condition, are plotted on each of the 15 subplots. The first time history, a "dashed / dashed-dotted" trace, represents the "mean ± one standard deviation" of the *fully functional* aircraft response. The second time history is a "solid line / dotted" trace and represents the response of the *impaired* aircraft at the given impairment condition.

Second Impairment

	LS (50%)	RS (50%)	LF (50%)	RF (50%)	RUD (50%)	AOA (100%)	Q (100%)	A_n (100%)	P (100%)	R (100%)	A_y (100%)
LS (50%)	**fail501.500**	fail501.502	fail501.503	fail501.504	fail501.505	fail501.06	fail501.07	fail501.08	fail501.09	fail501.010	fail501.011
RS (50%)	fail502.501	**fail502.500**	fail502.503	fail502.504	fail502.505	fail502.06	fail502.07	fail502.08	fail502.09	fail502.010	fail502.011
LF (50%)	fail503.501	fail503.502	**fail503.500**	fail503.504	fail503.505	fail503.06	fail503.07	fail503.08	fail503.09	fail503.010	fail503.011
RF (50%)	fail504.501	fail504.502	fail504.503	**fail504.500**	fail504.505	fail504.06	fail504.07	fail504.08	fail504.09	fail504.010	fail504.011
RUD (50%)	fail505.501	fail505.502	fail505.503	fail505.504	**fail505.500**	fail505.06	fail505.07	fail505.08	fail505.09	fail505.010	fail505.011

Table H.3 A Listing of All State Plots Found in Appendix H.3 by Failure Case

H.3

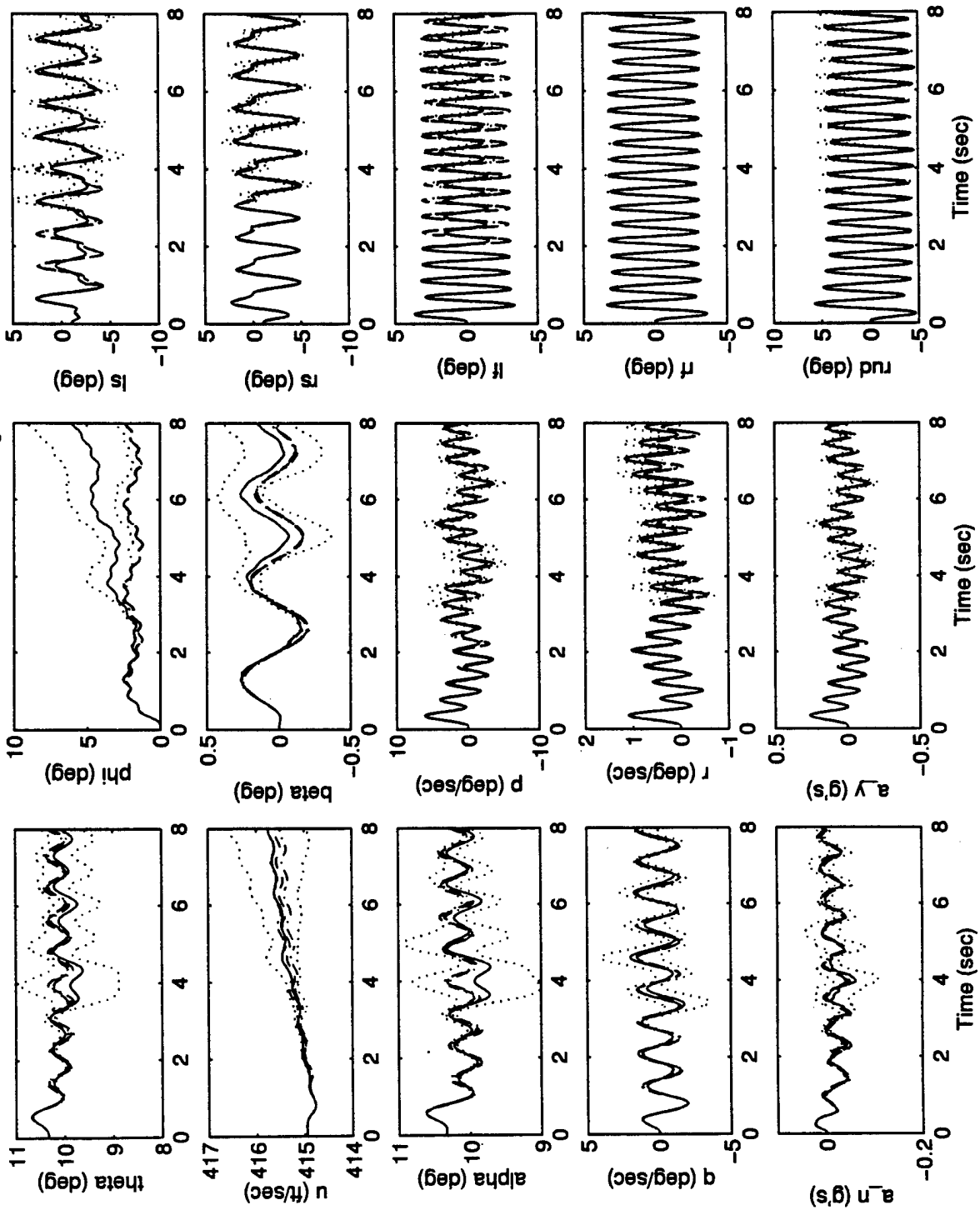dual-failure fail501.500 with reconfiguration

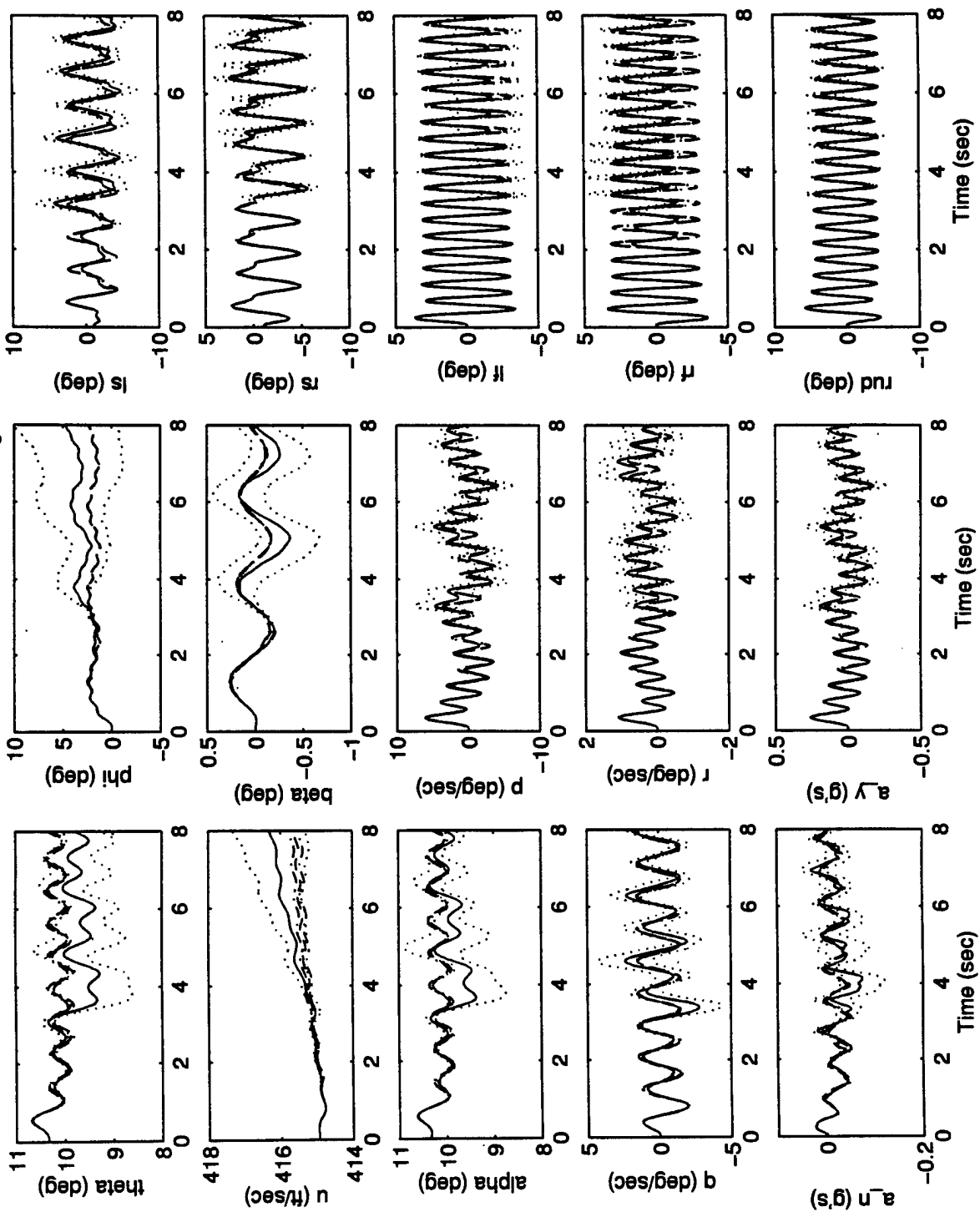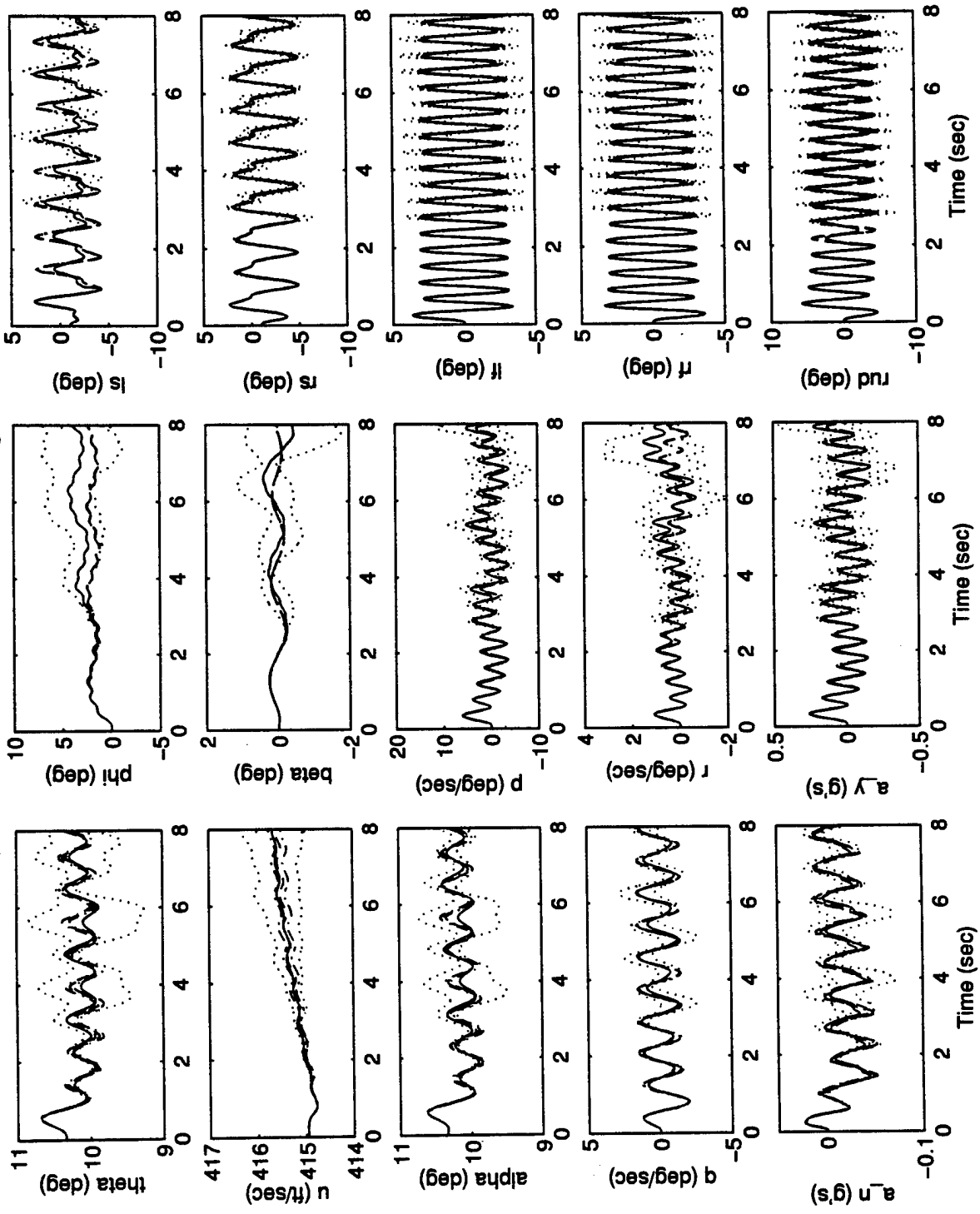dual-failure fail501.502 with reconfiguration
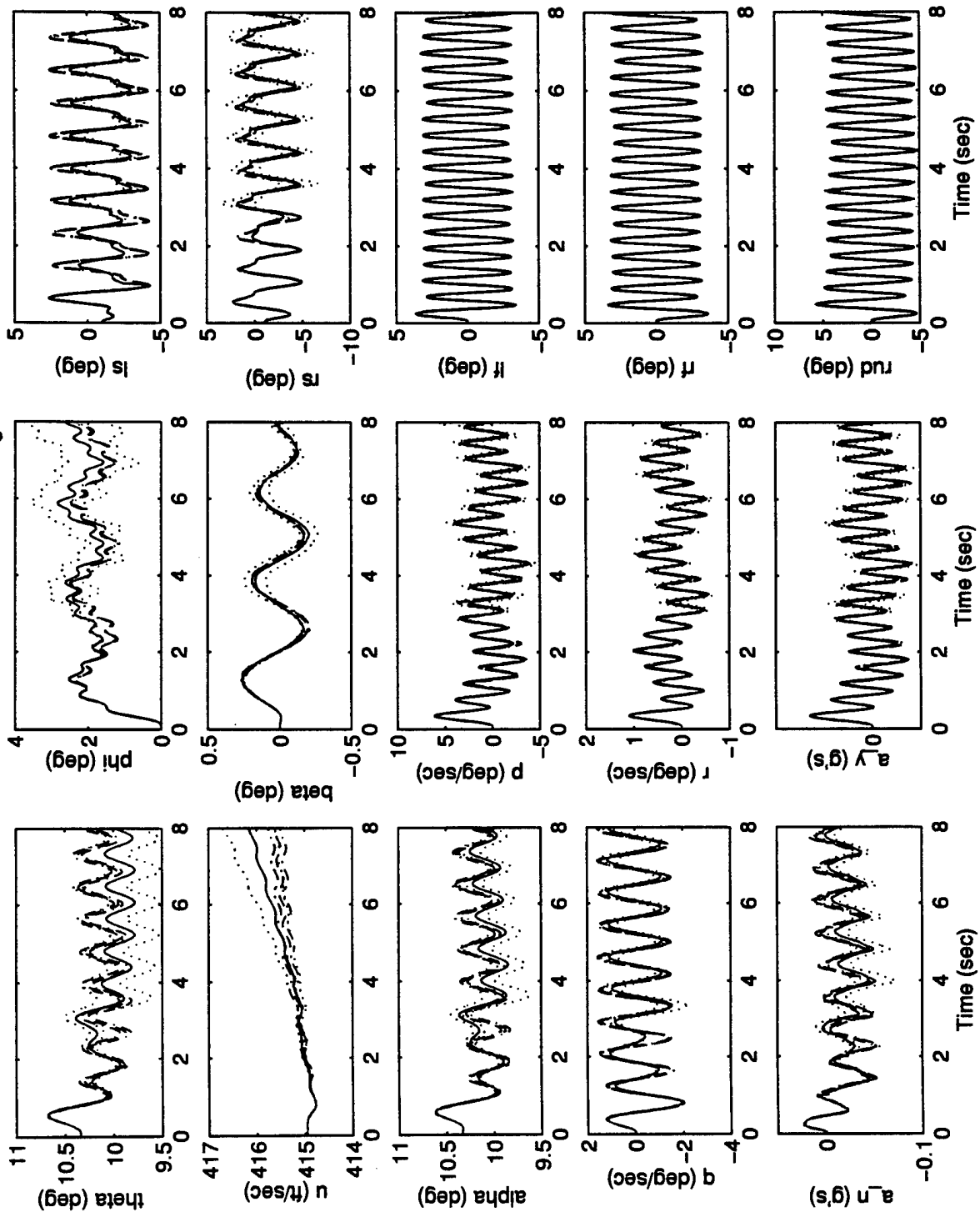
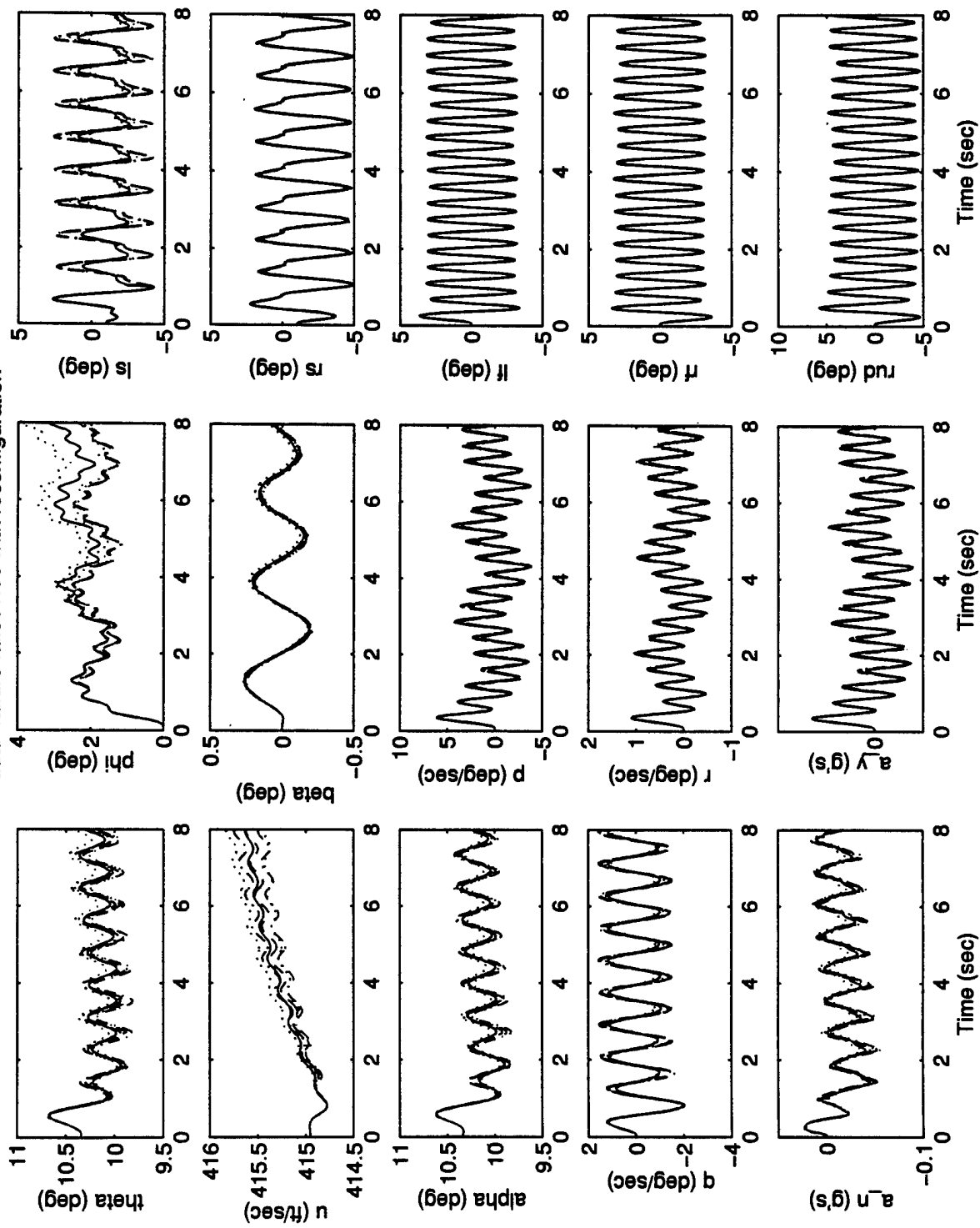dual-failure fail501.503 with reconfiguration

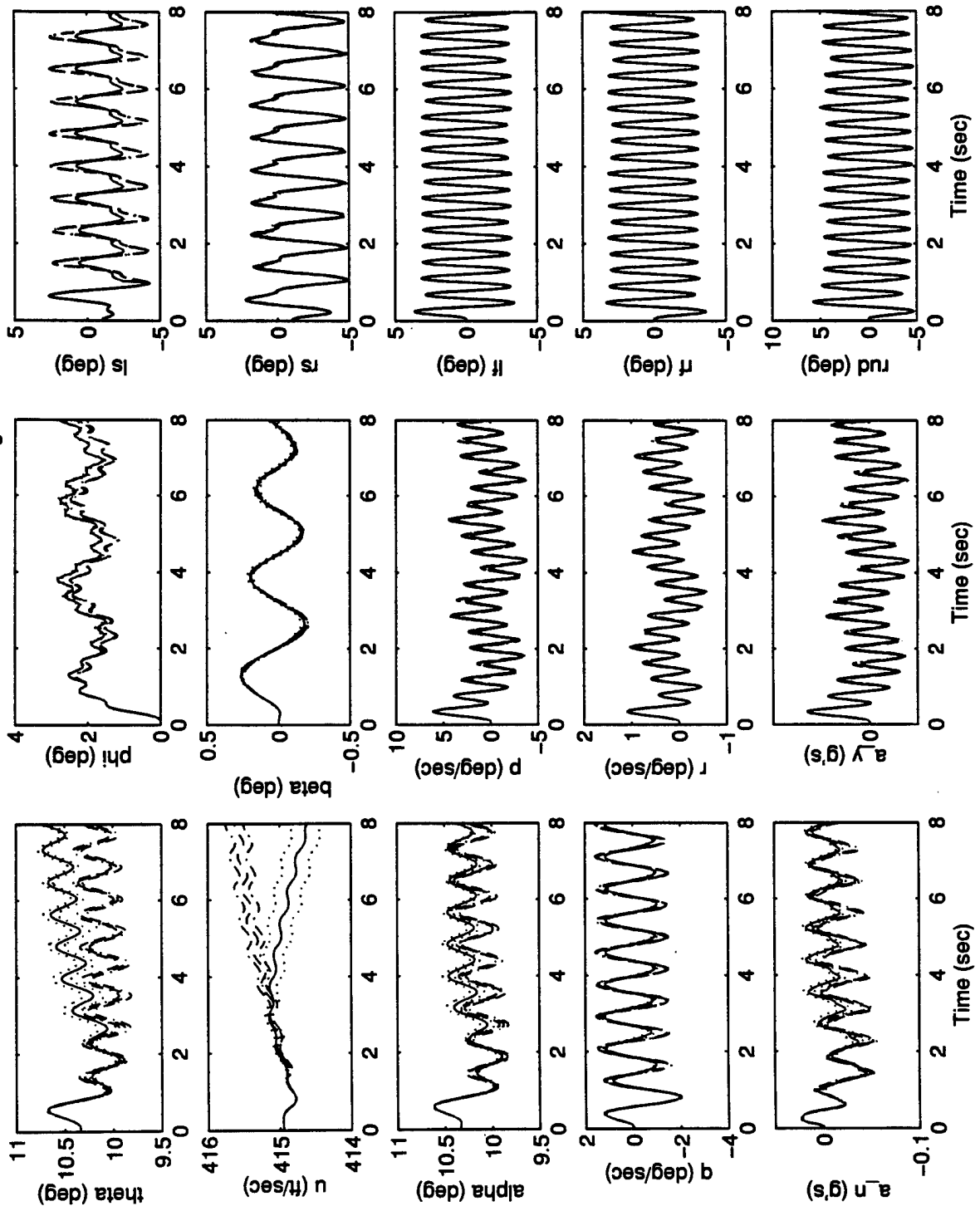dual-failure fail501.504 with reconfiguration
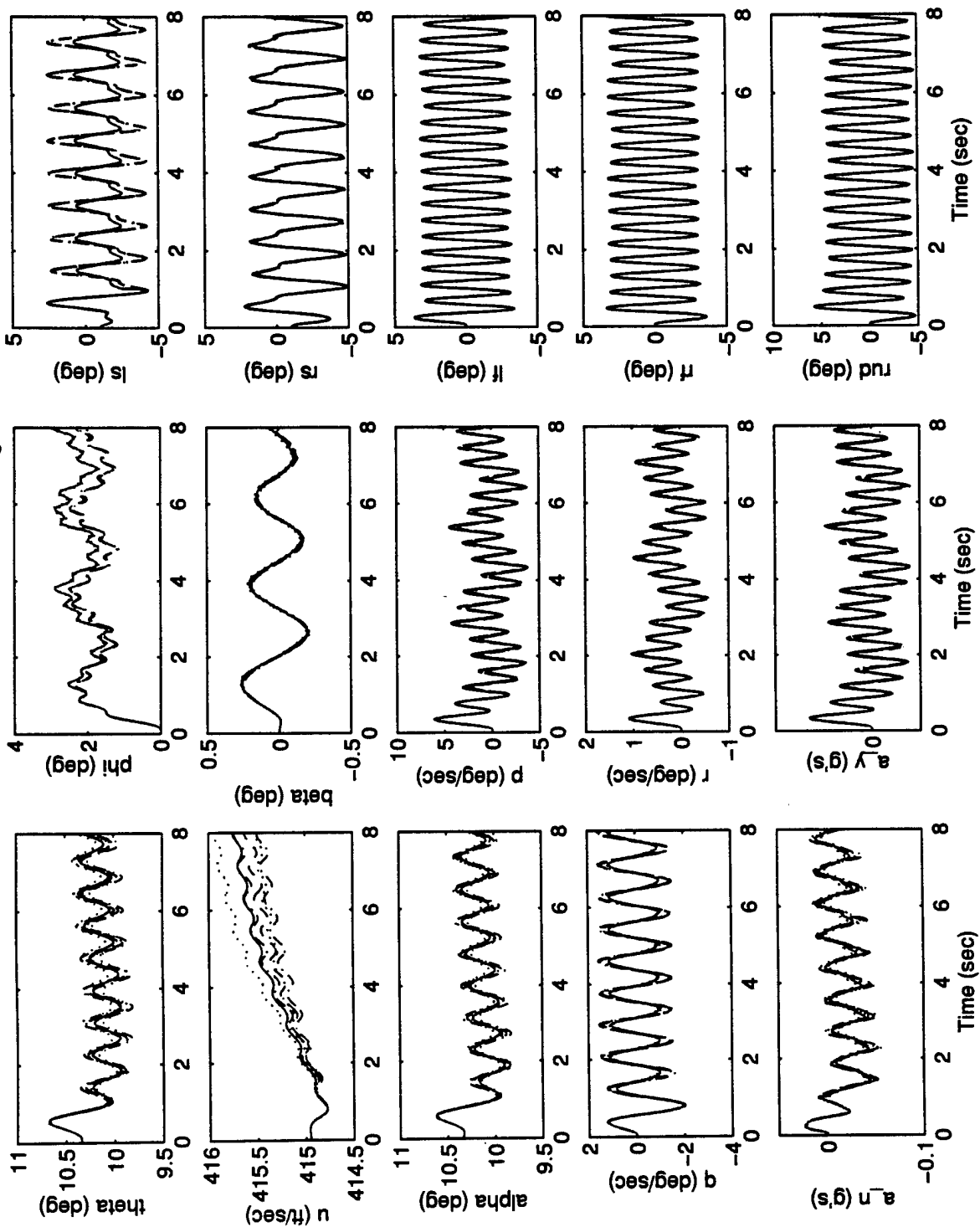
dual-failure fail501.505 with reconfiguration

dual-failure fail501.06 with reconfiguration

dual-failure fail501.07 with reconfiguration

dual-failure fail501.08 with reconfiguration

dual-failure fail501.09 with reconfiguration

dual-failure fail501.010 with reconfiguration

dual–failure fail501.011 with reconfiguration

dual–failure fail502.500 with reconfiguration

dual-failure fail502.501 with reconfiguration

dual–failure fail502.503 with reconfiguration

dual-failure fail502.504 with reconfiguration

dual–failure fail502.505 with reconfiguration
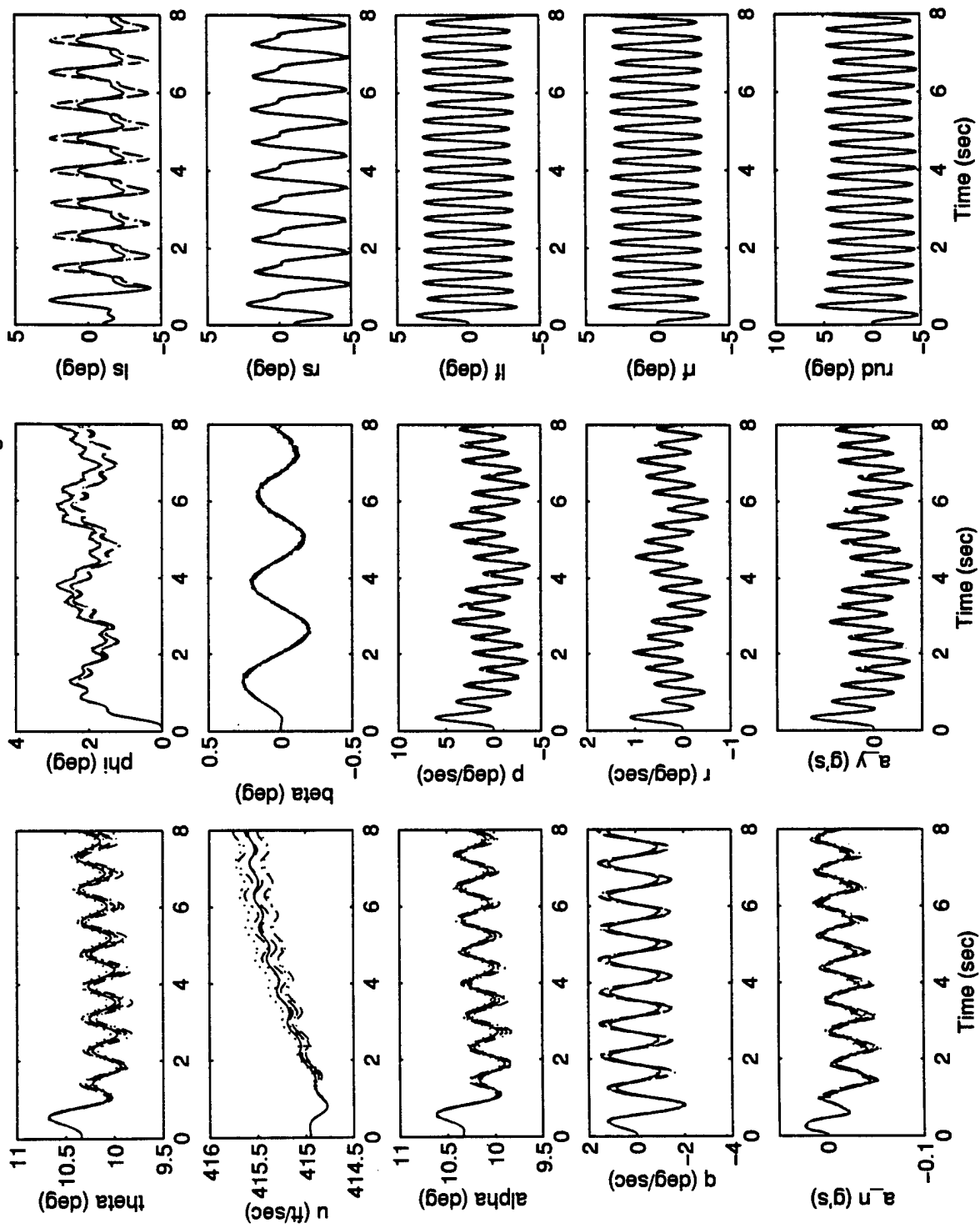
dual-failure fail502.06 with reconfiguration

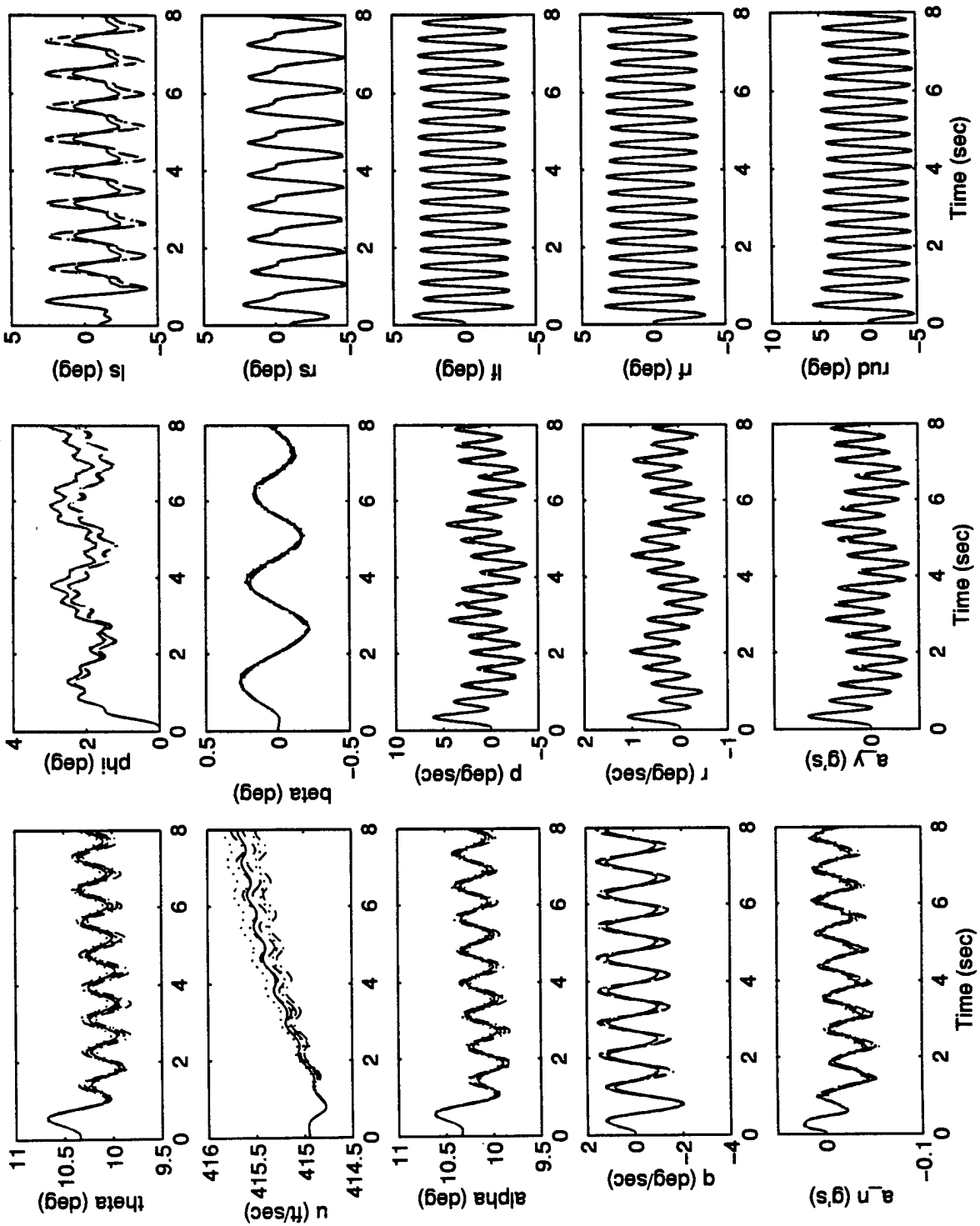dual–failure fail502.07 with reconfiguration

dual-failure fail502.08 with reconfiguration

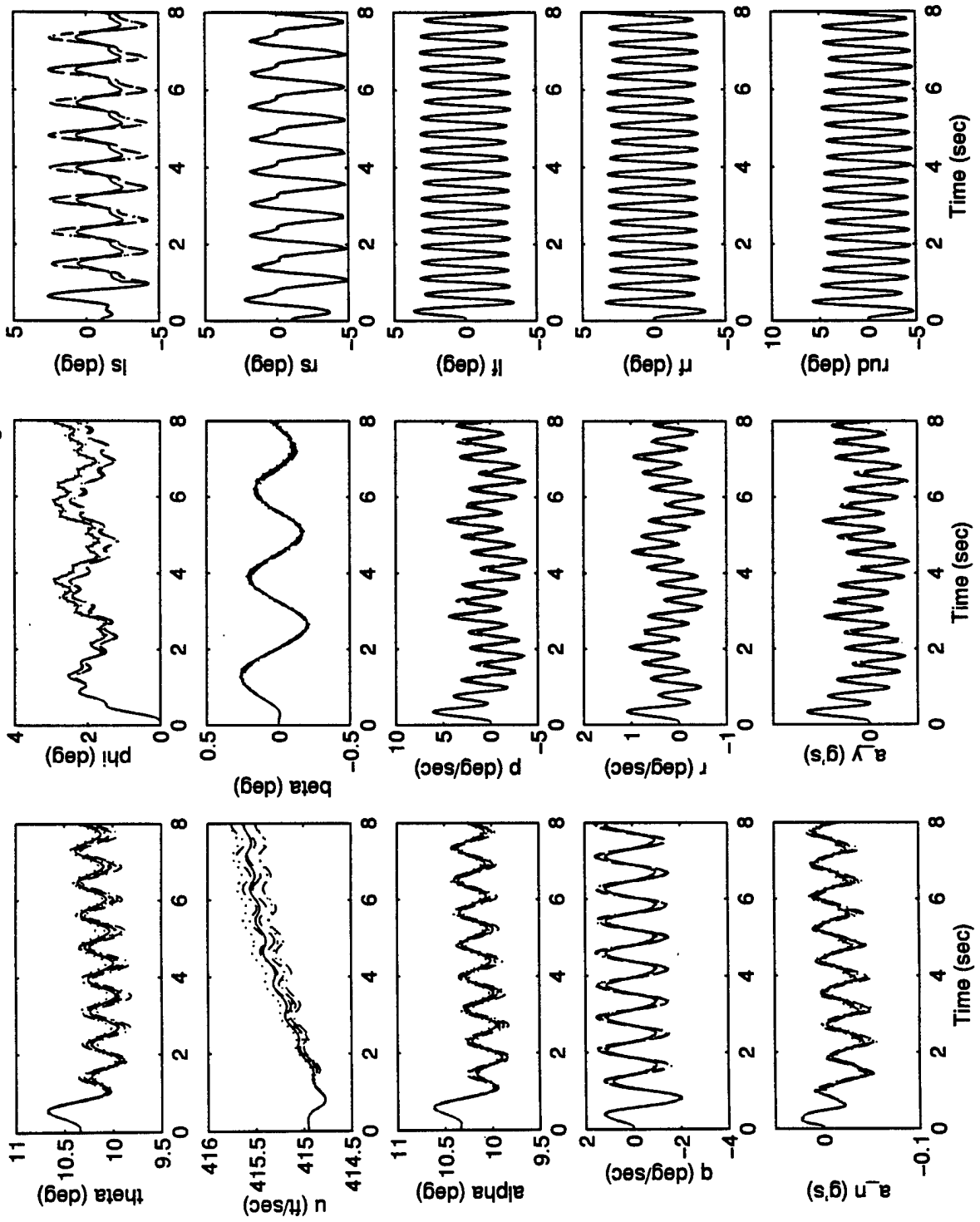dual-failure fail502.09 with reconfiguration
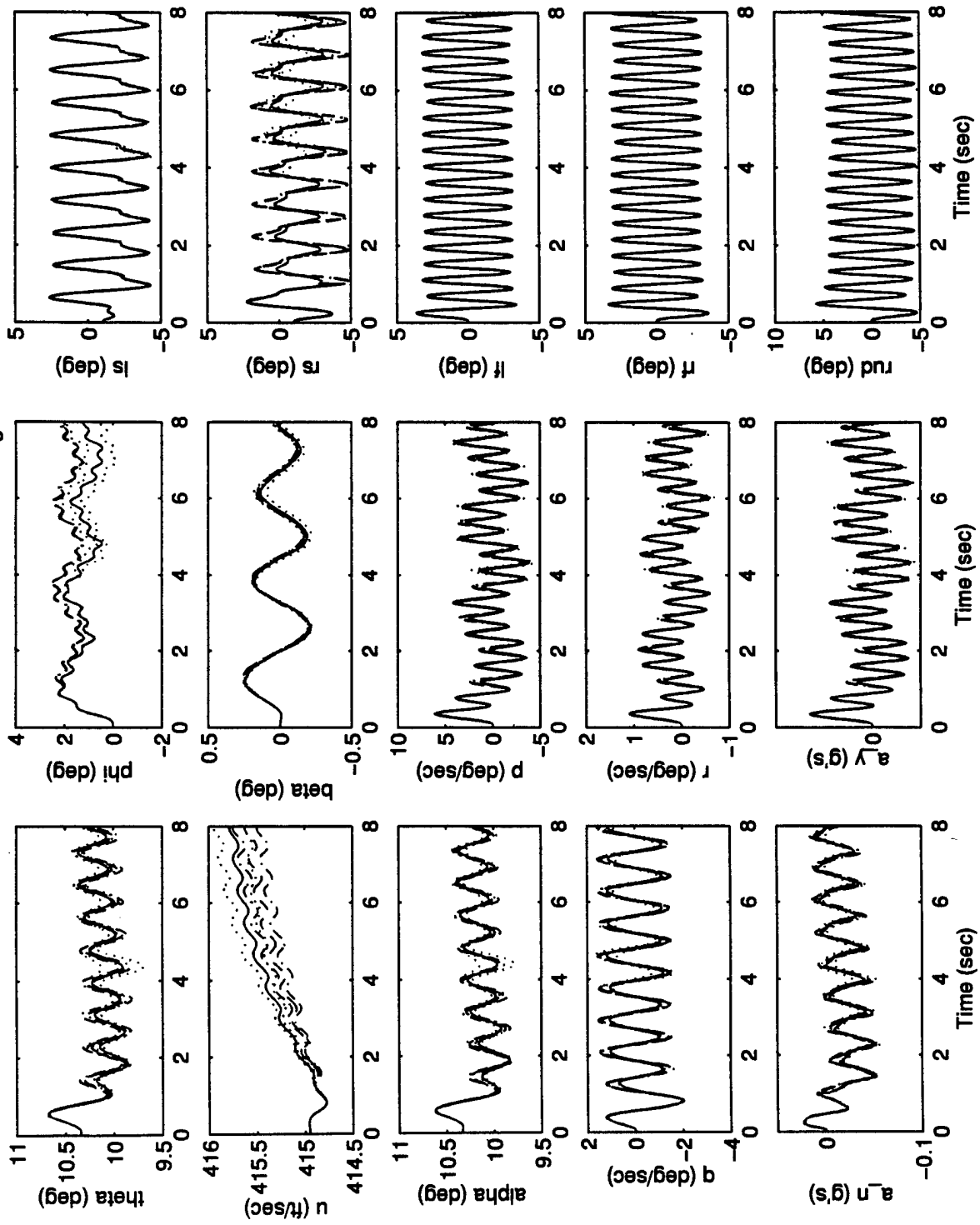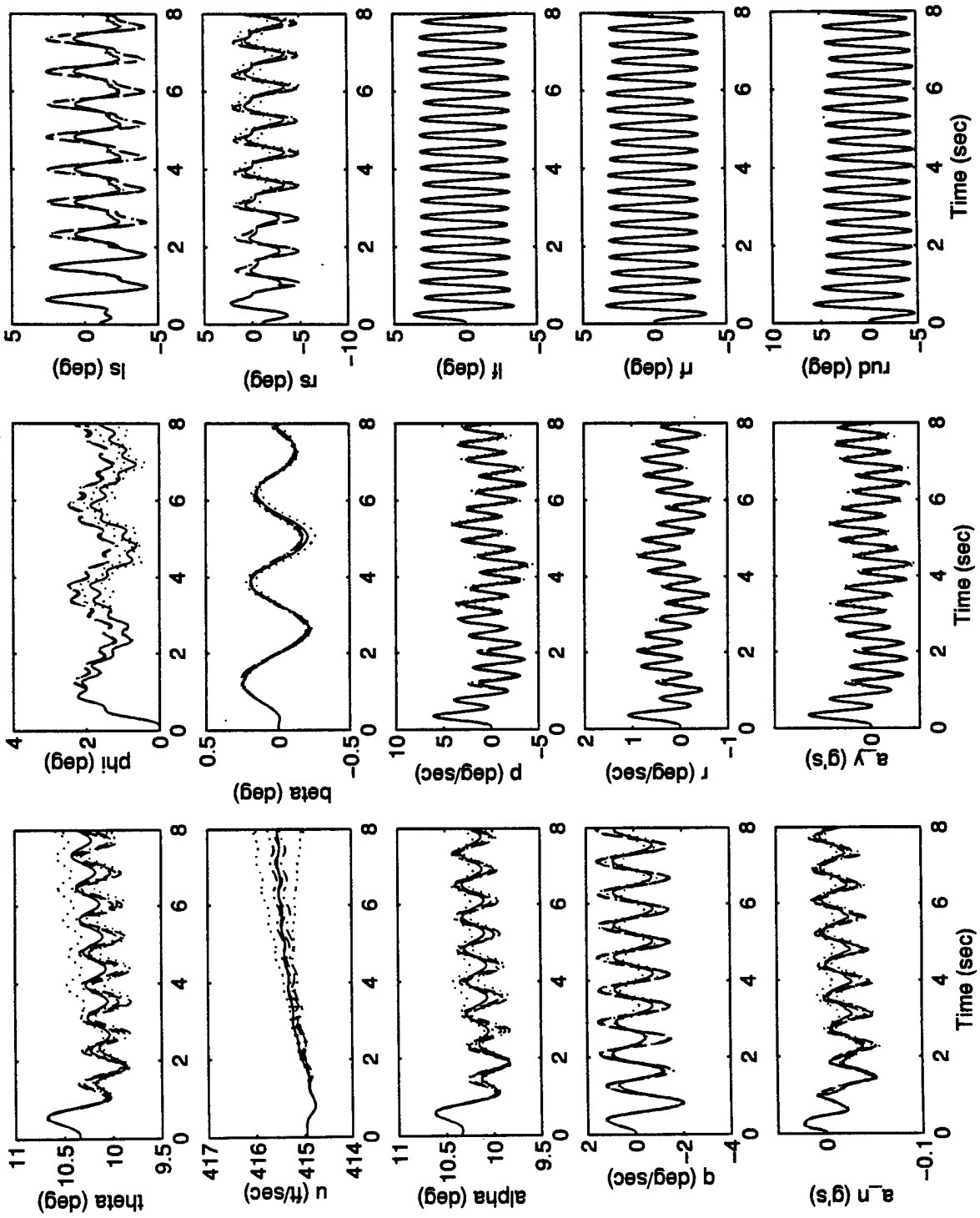
dual-failure fail502.010 with reconfiguration
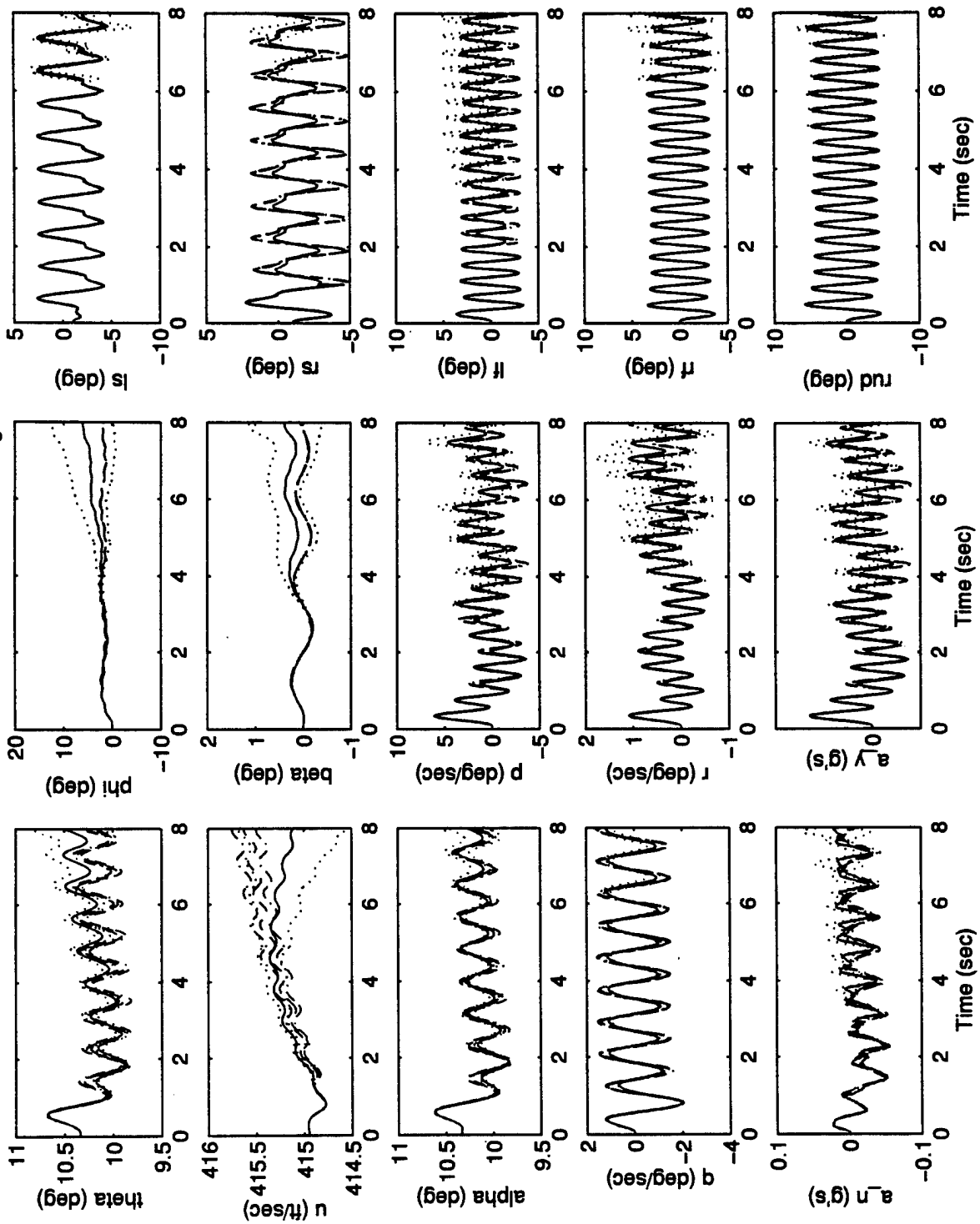
dual–failure fail502.011 with reconfiguration

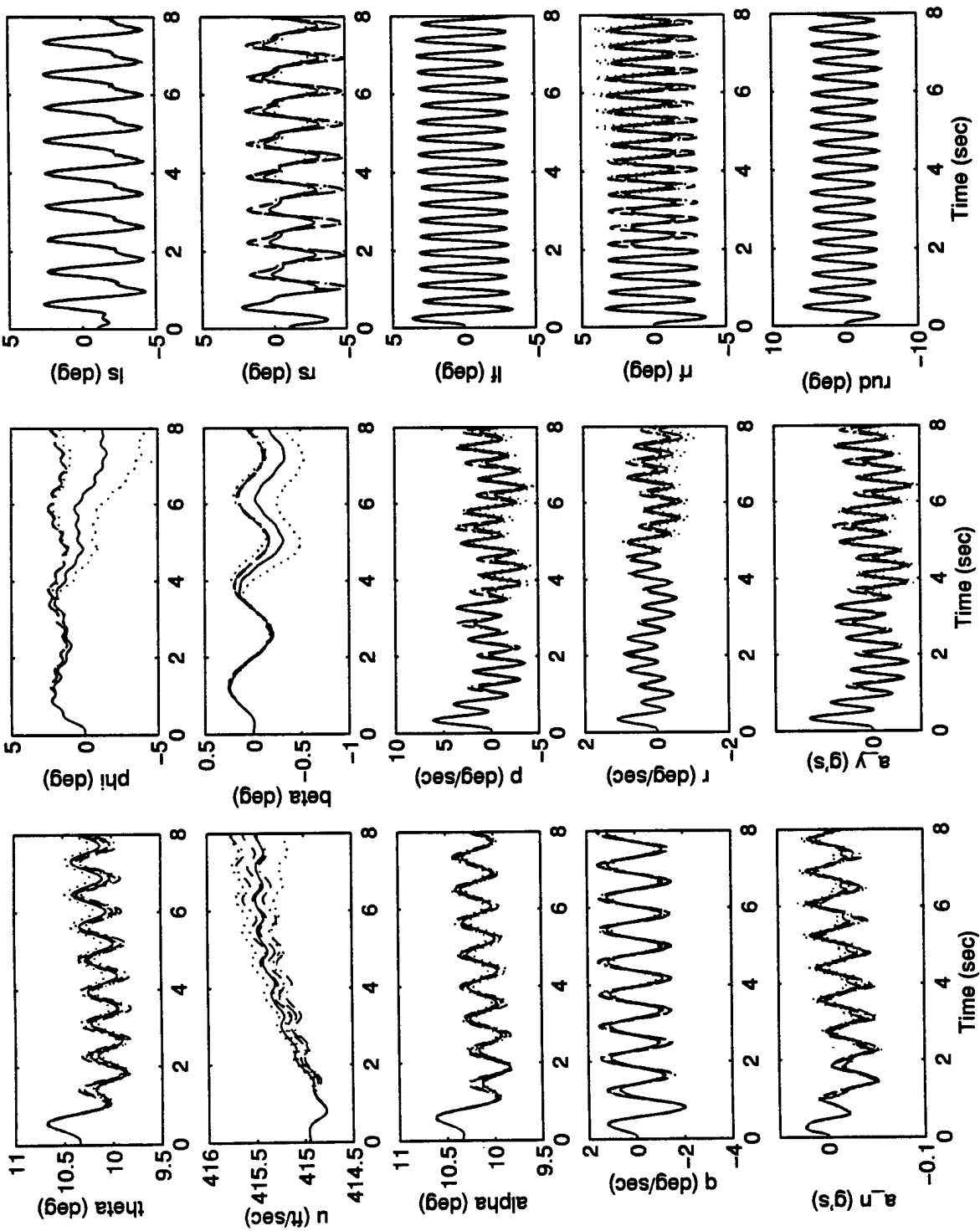dual-failure fail503.500 with reconfiguration

dual-failure fail503.501 with reconfiguration

dual-failure fail503.502 with reconfiguration

dual-failure fail503.504 with reconfiguration

dual-failure fail503.505 with reconfiguration

dual-failure fail503.06 with reconfiguration

dual-failure fail503.07 with reconfiguration

dual-failure fail503.08 with reconfiguration

dual-failure fail503.09 with reconfiguration

dual-failure fail503.010 with reconfiguration

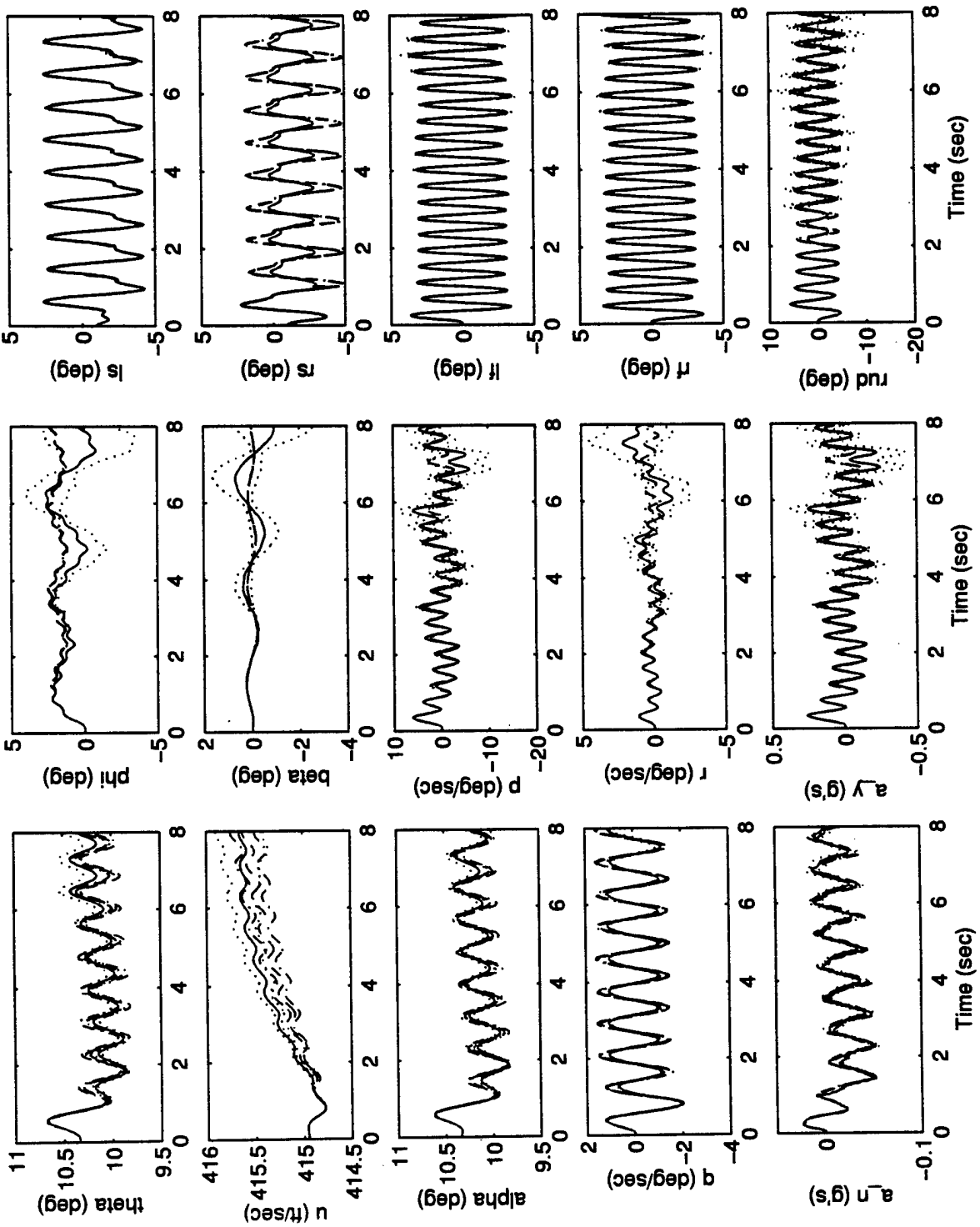dual-failure fail503.011 with reconfiguration

dual-failure fail504.500 with reconfiguration

dual-failure fail504.501 with reconfiguration
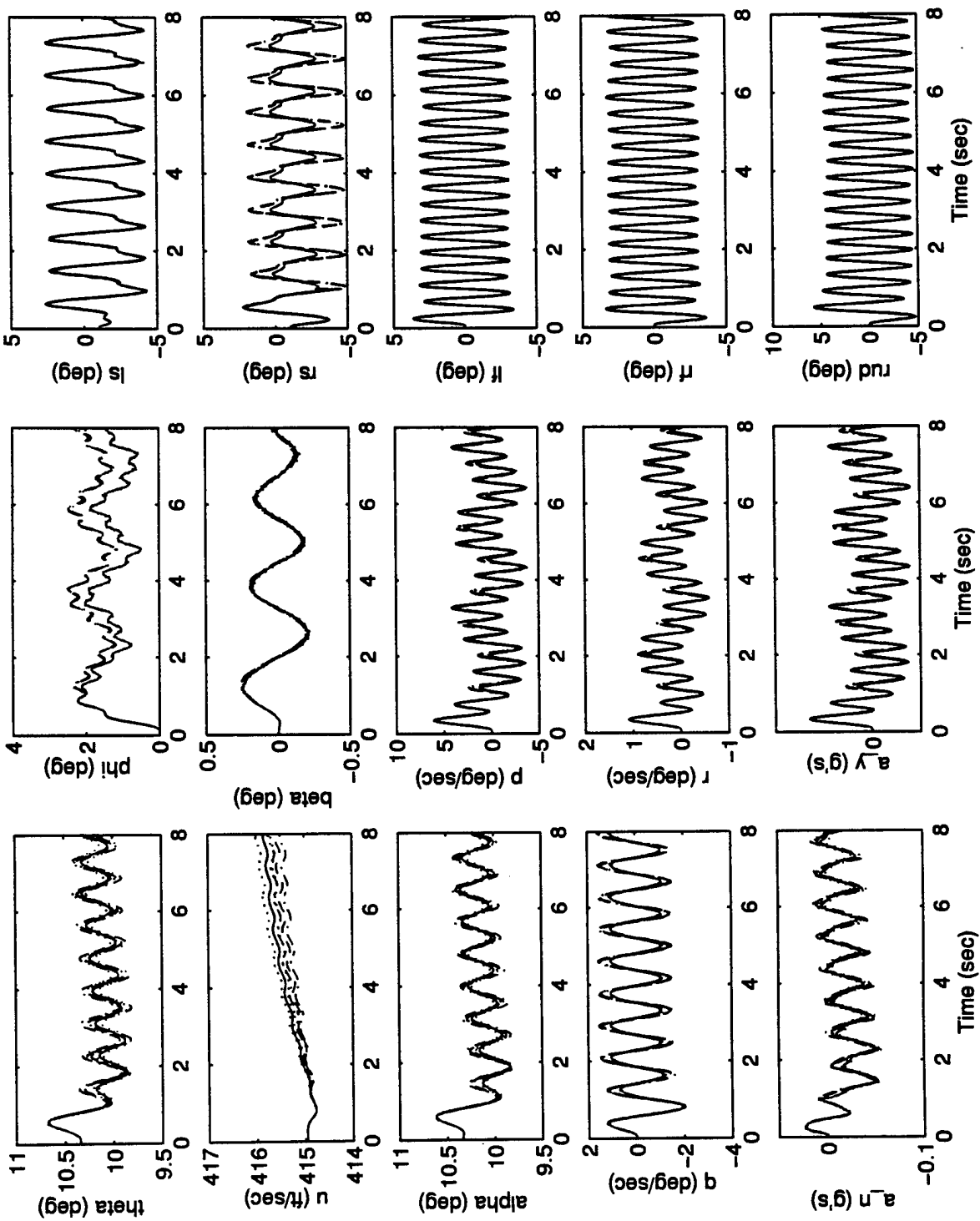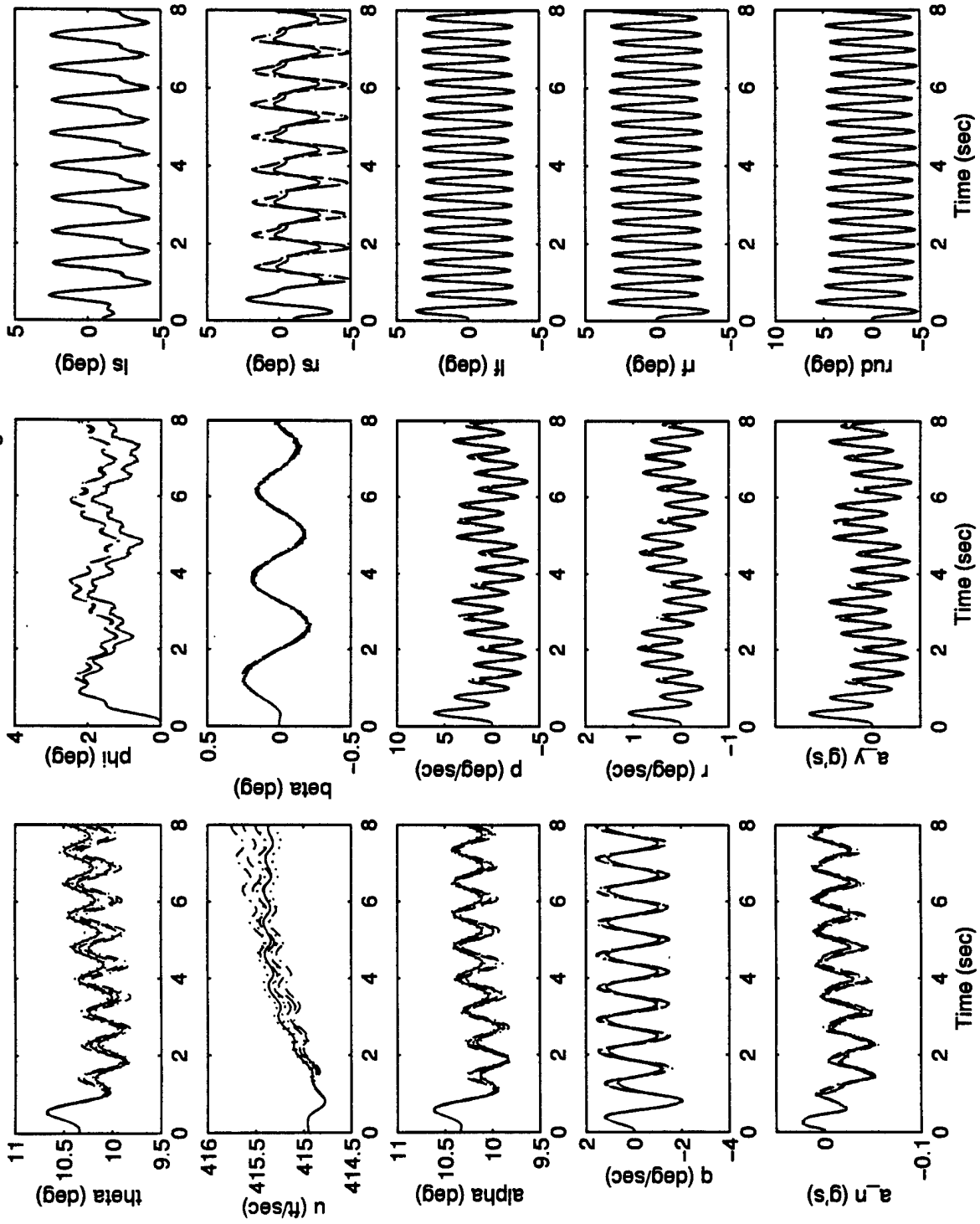
dual-failure fail504.502 with reconfiguration

dual-failure fail504.503 with reconfiguration

dual–failure fail504.505 with reconfiguration

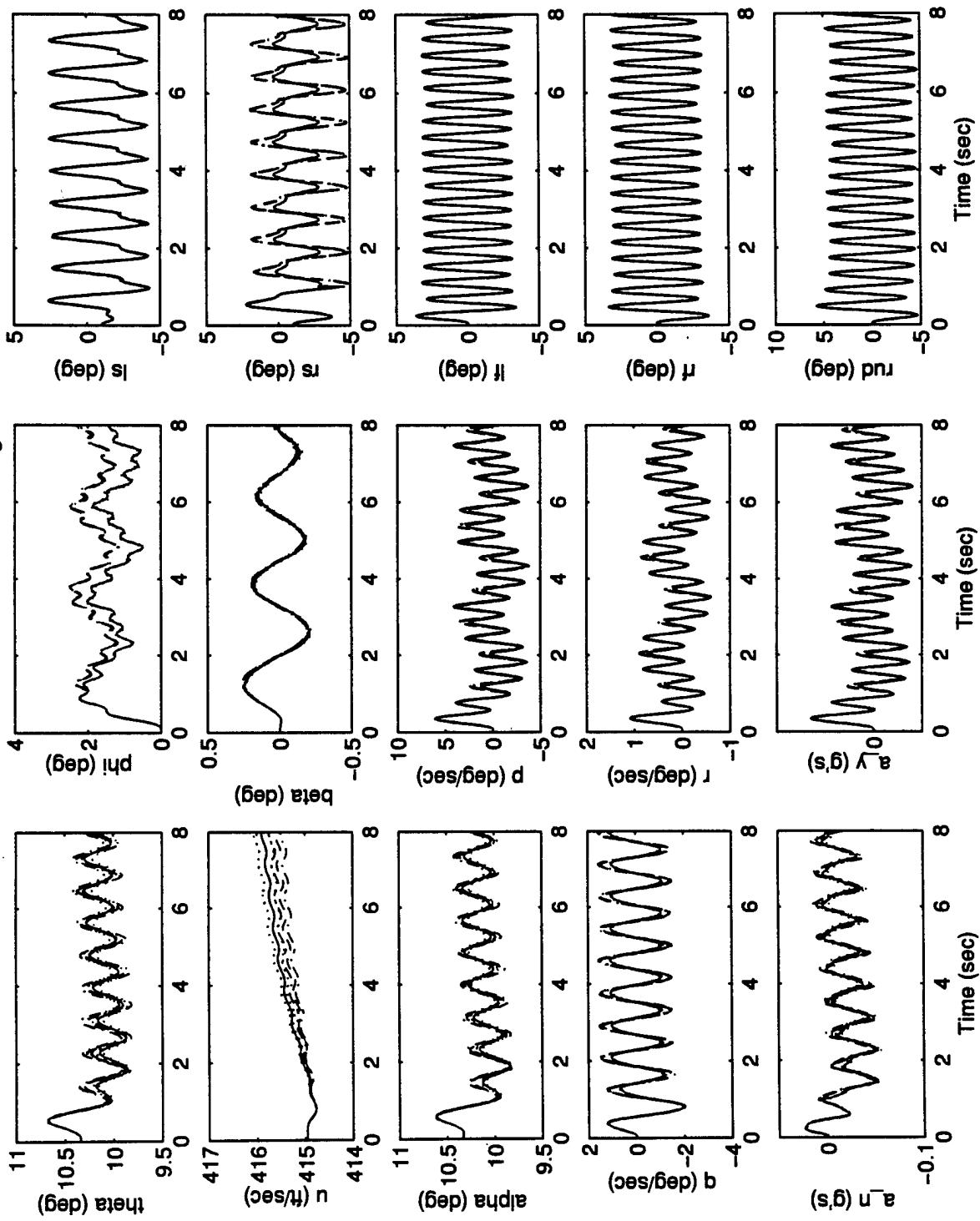dual-failure fail504.06 with reconfiguration

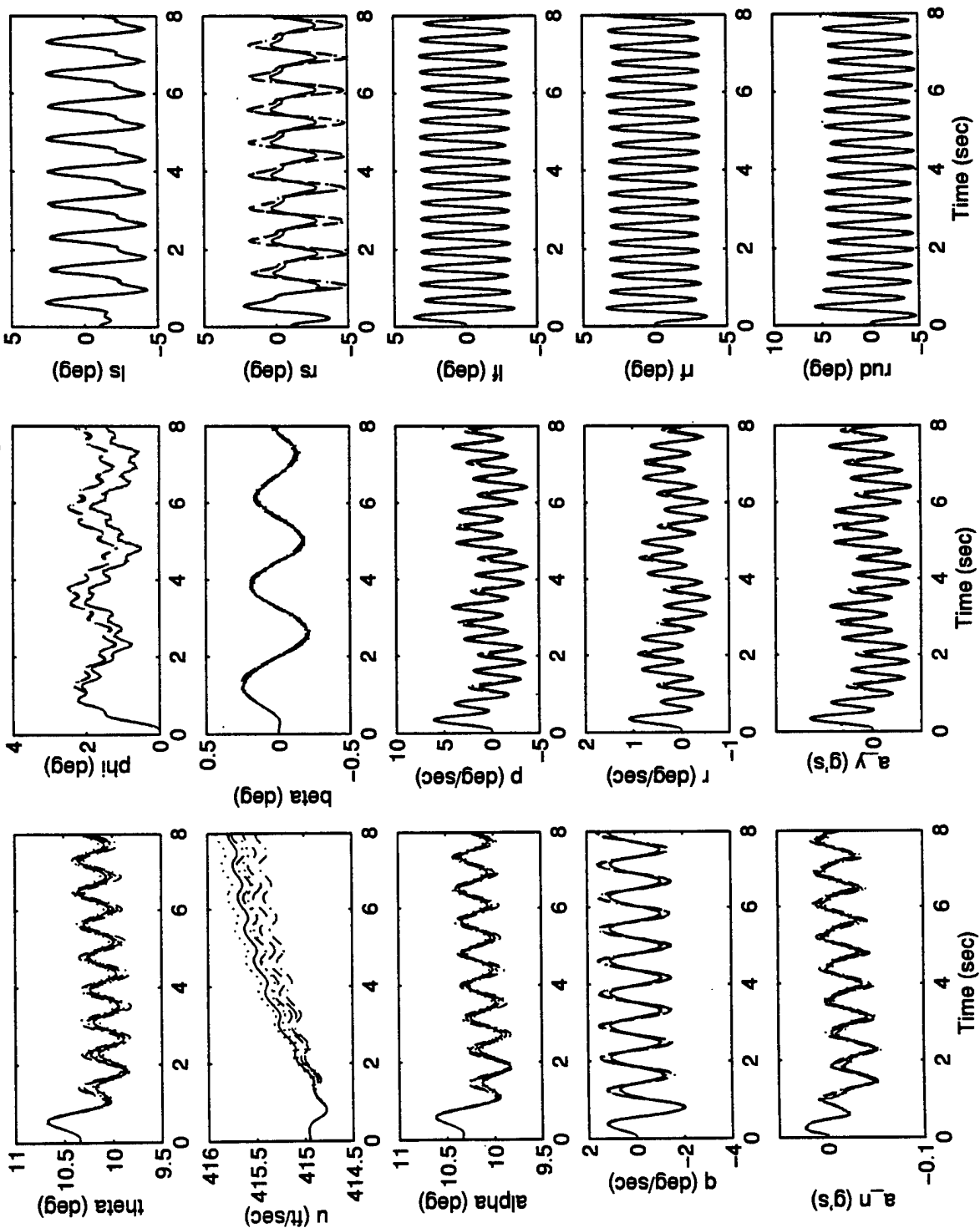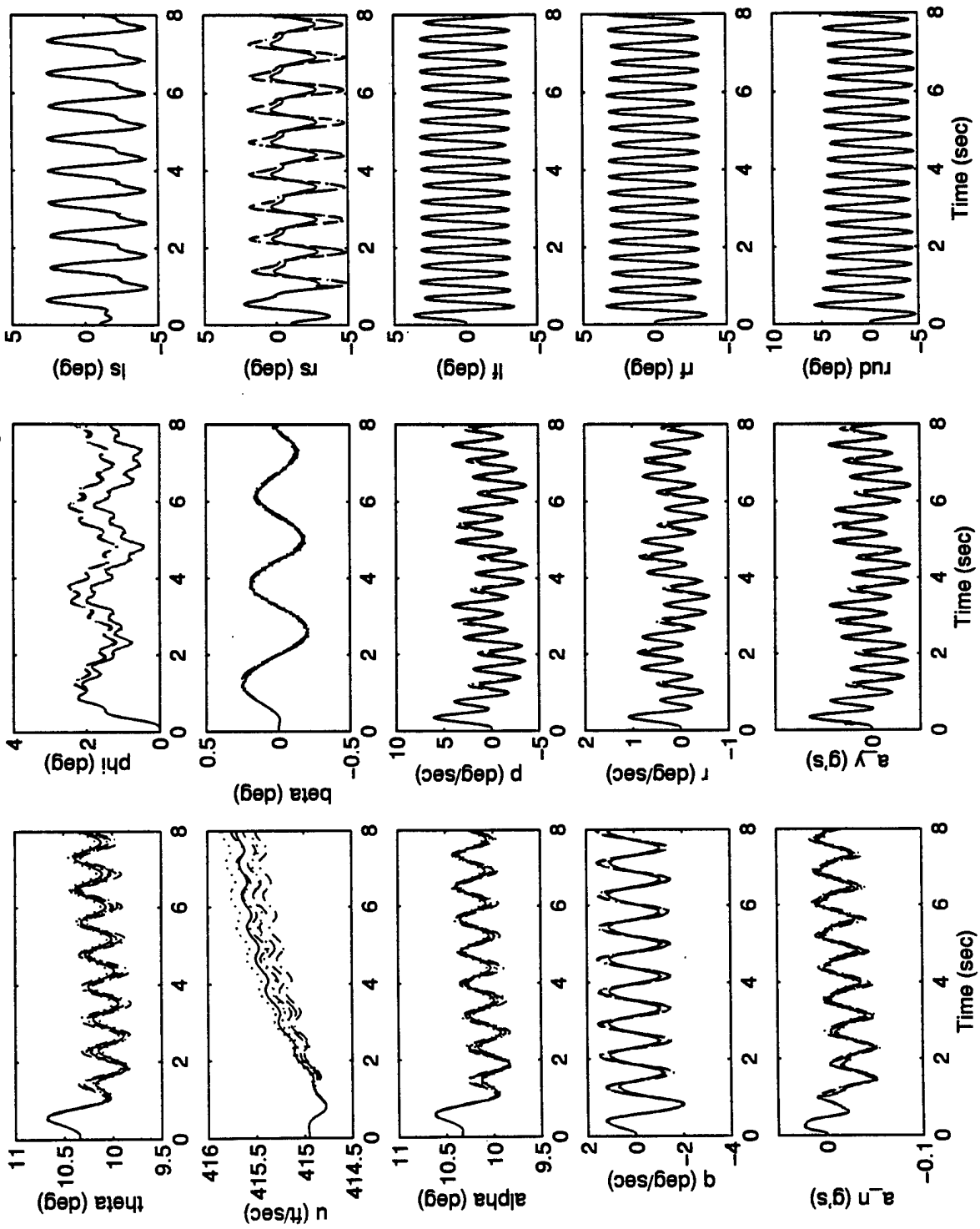dual-failure fail504.07 with reconfiguration
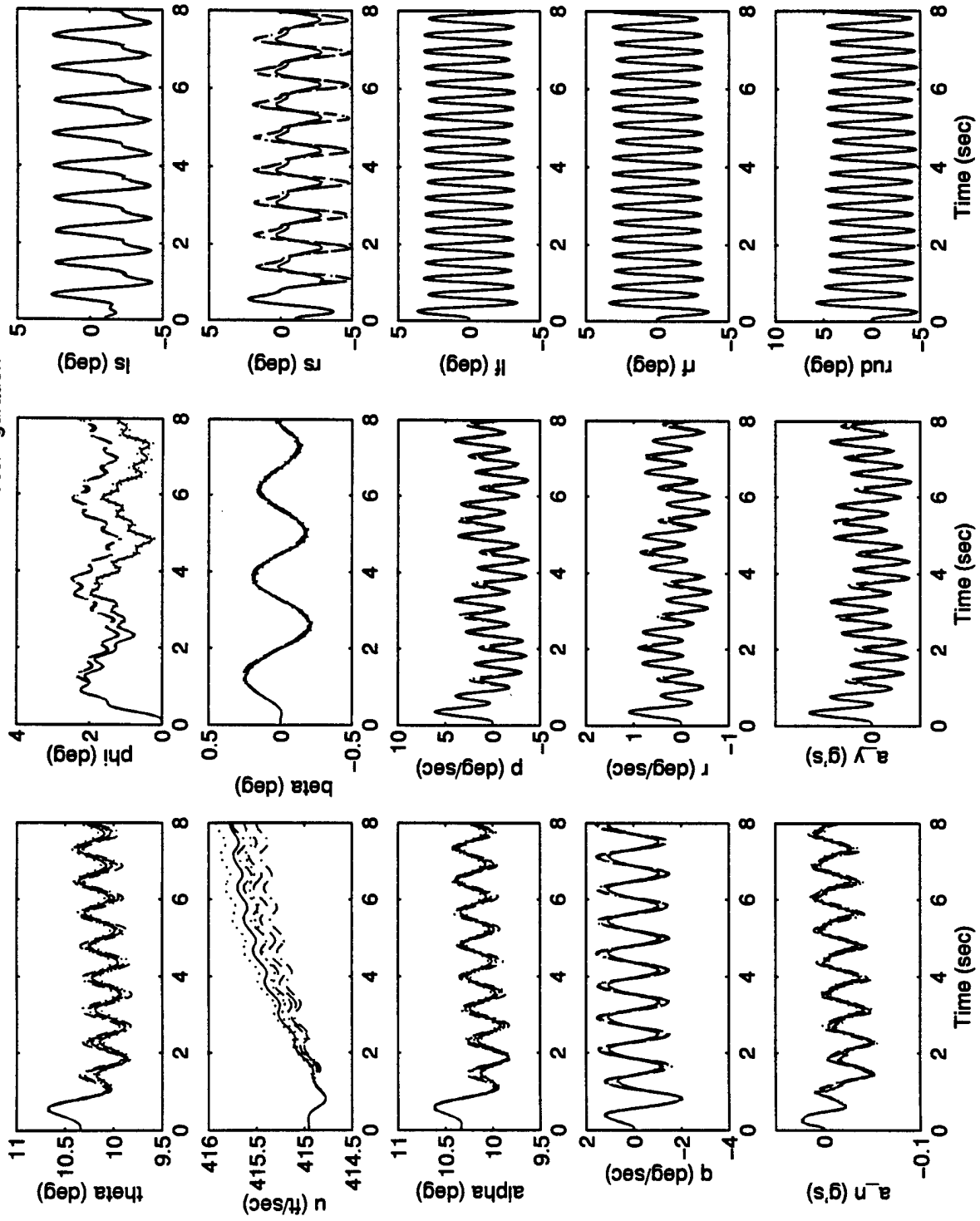
dual-failure fail504.08 with reconfiguration

dual-failure fail504.09 with reconfiguration

dual-failure fail504.010 with reconfiguration

dual-failure fail504.011 with reconfiguration

dual-failure fail505.500 with reconfiguration

dual-failure fail505.501 with reconfiguration

dual-failure fail505.502 with reconfiguration

dual-failure fail505.503 with reconfiguration

dual-failure fail505,504 with reconfiguration

dual-failure fail505.06 with reconfiguration

dual-failure fail505.07 with reconfiguration

dual-failure fail505.08 with reconfiguration

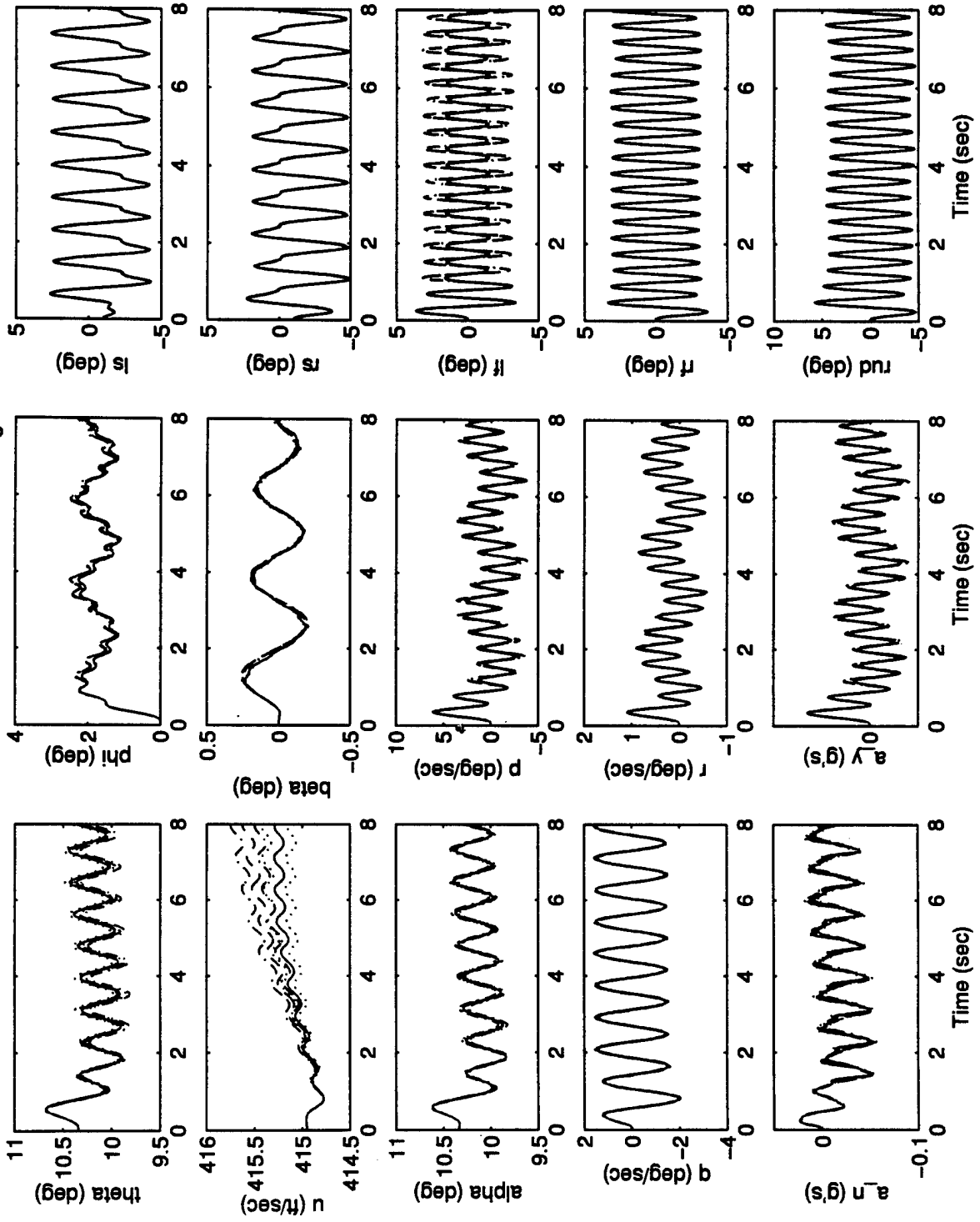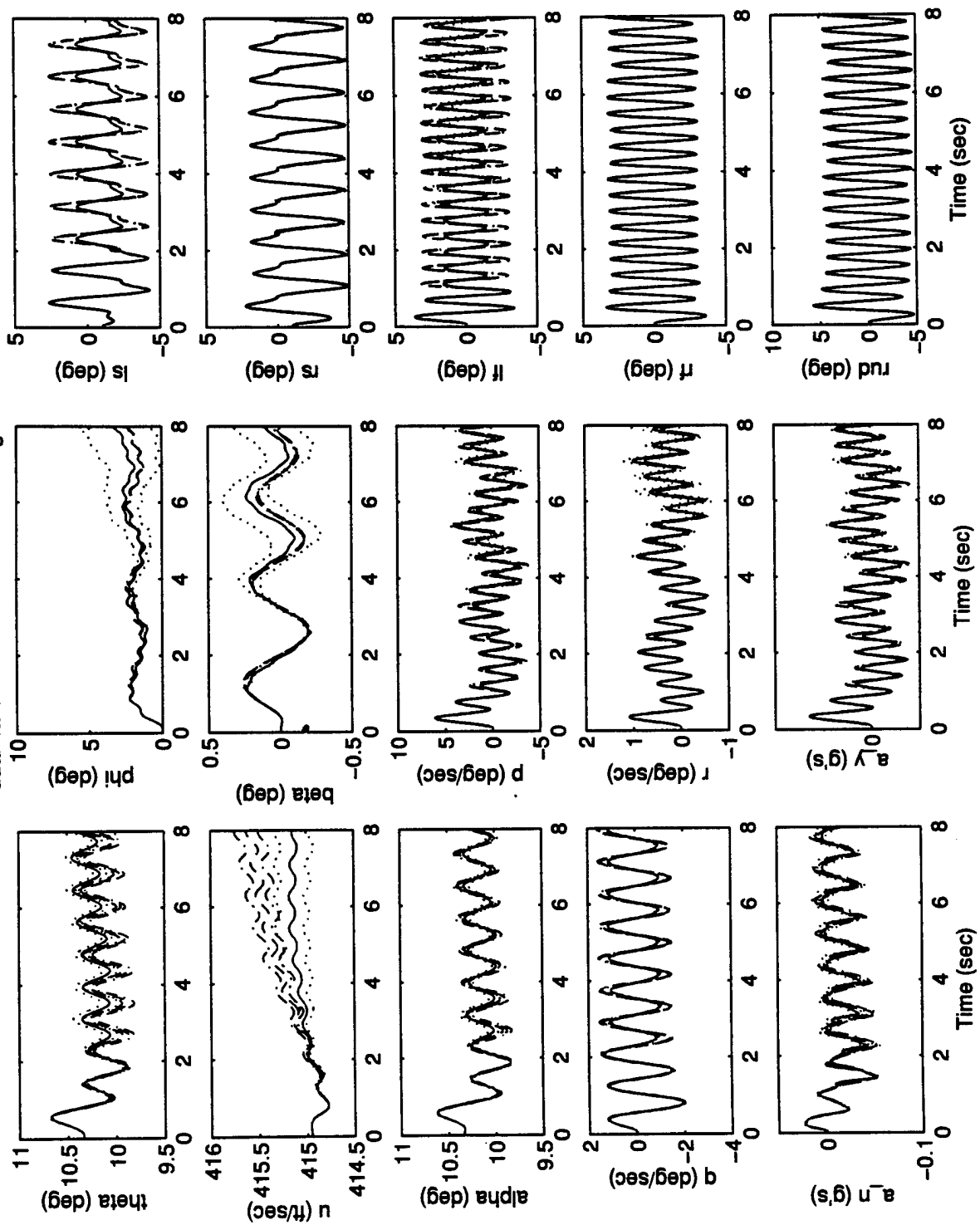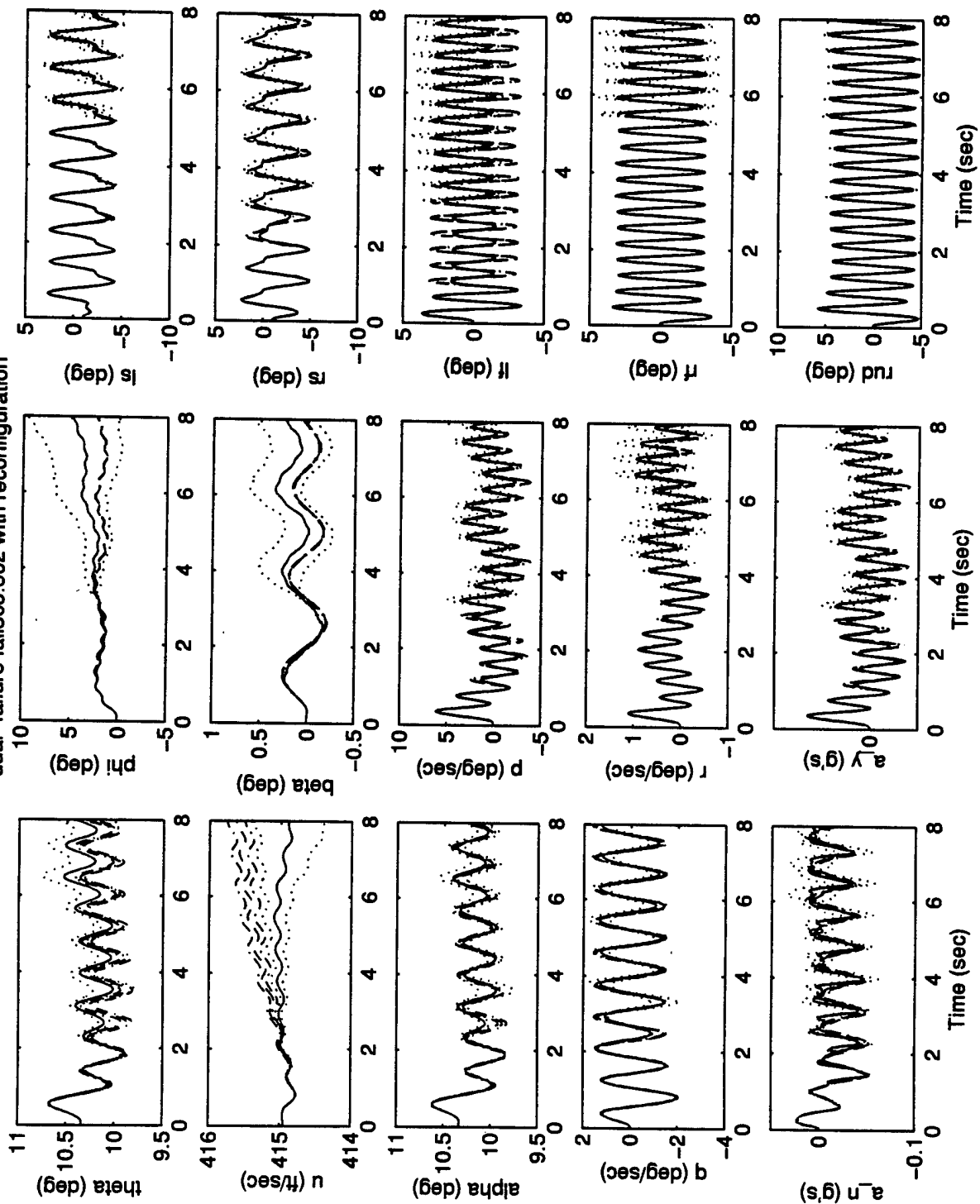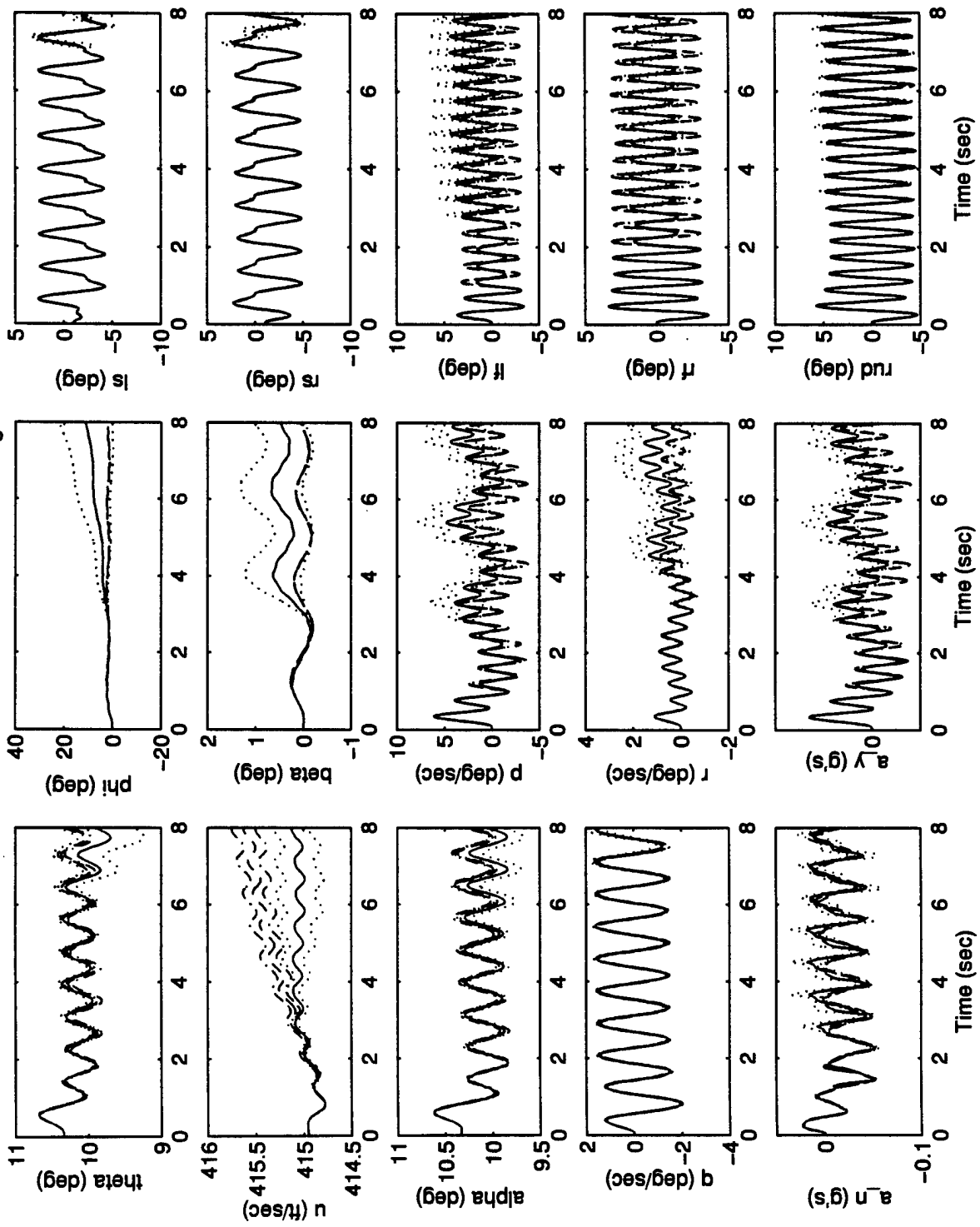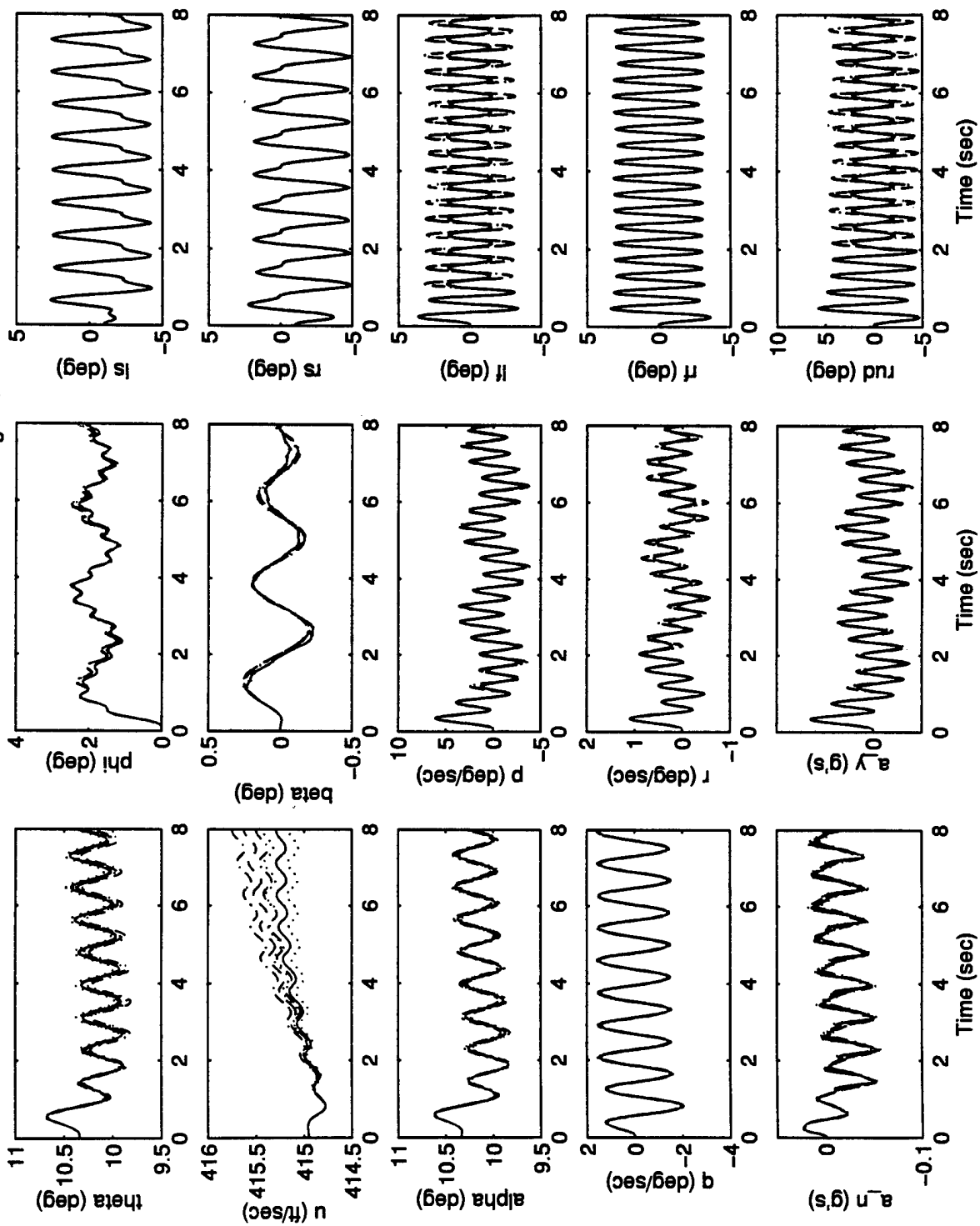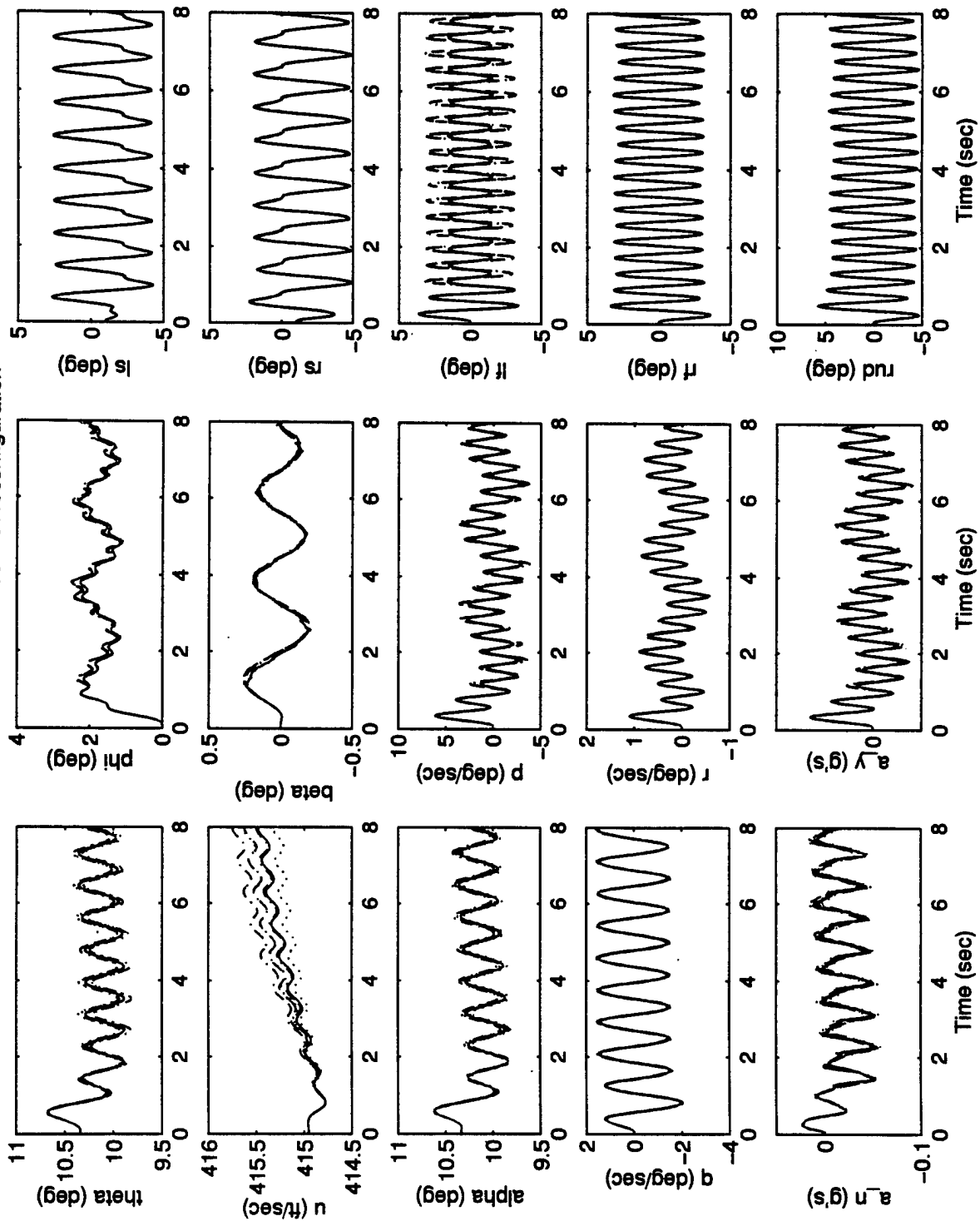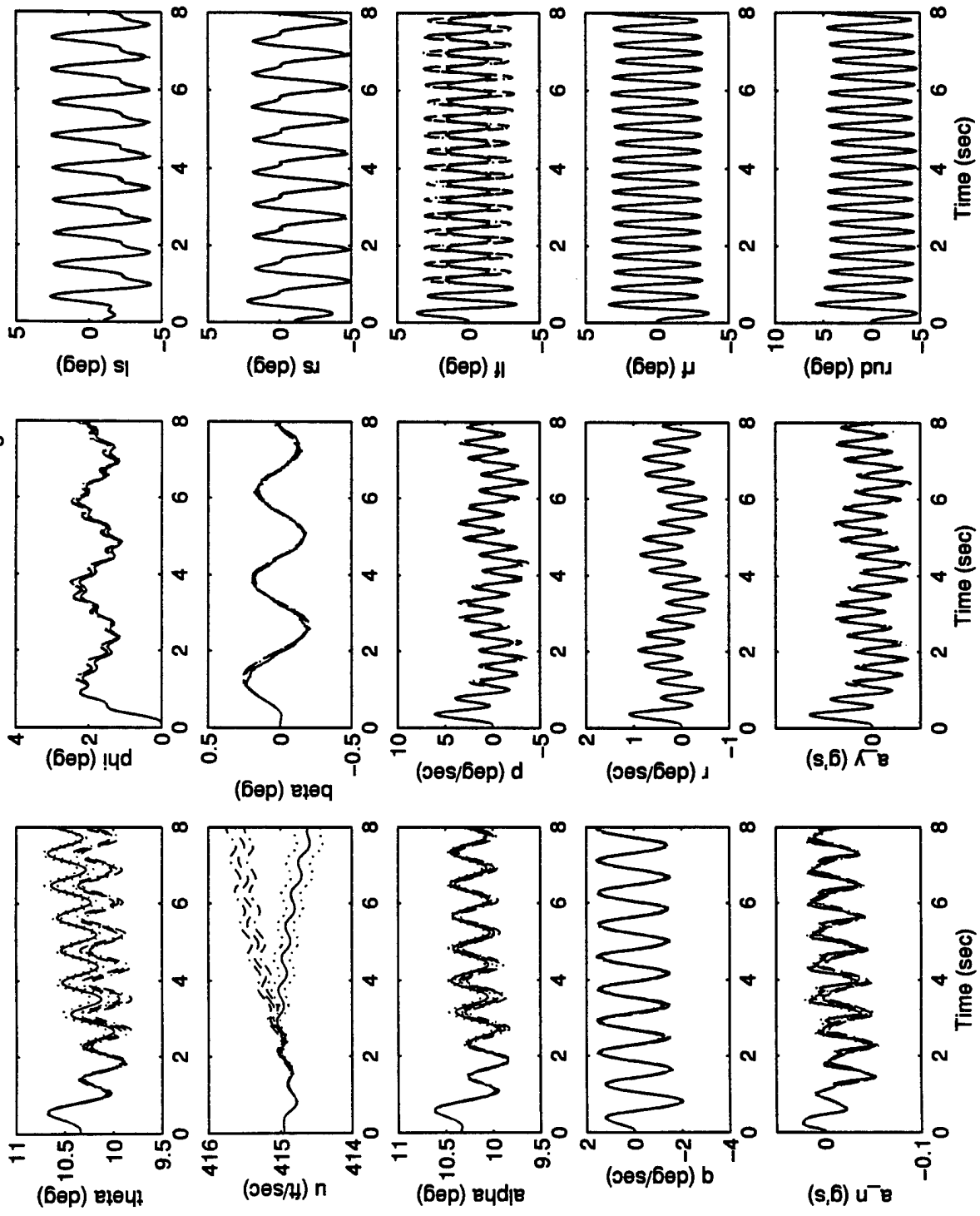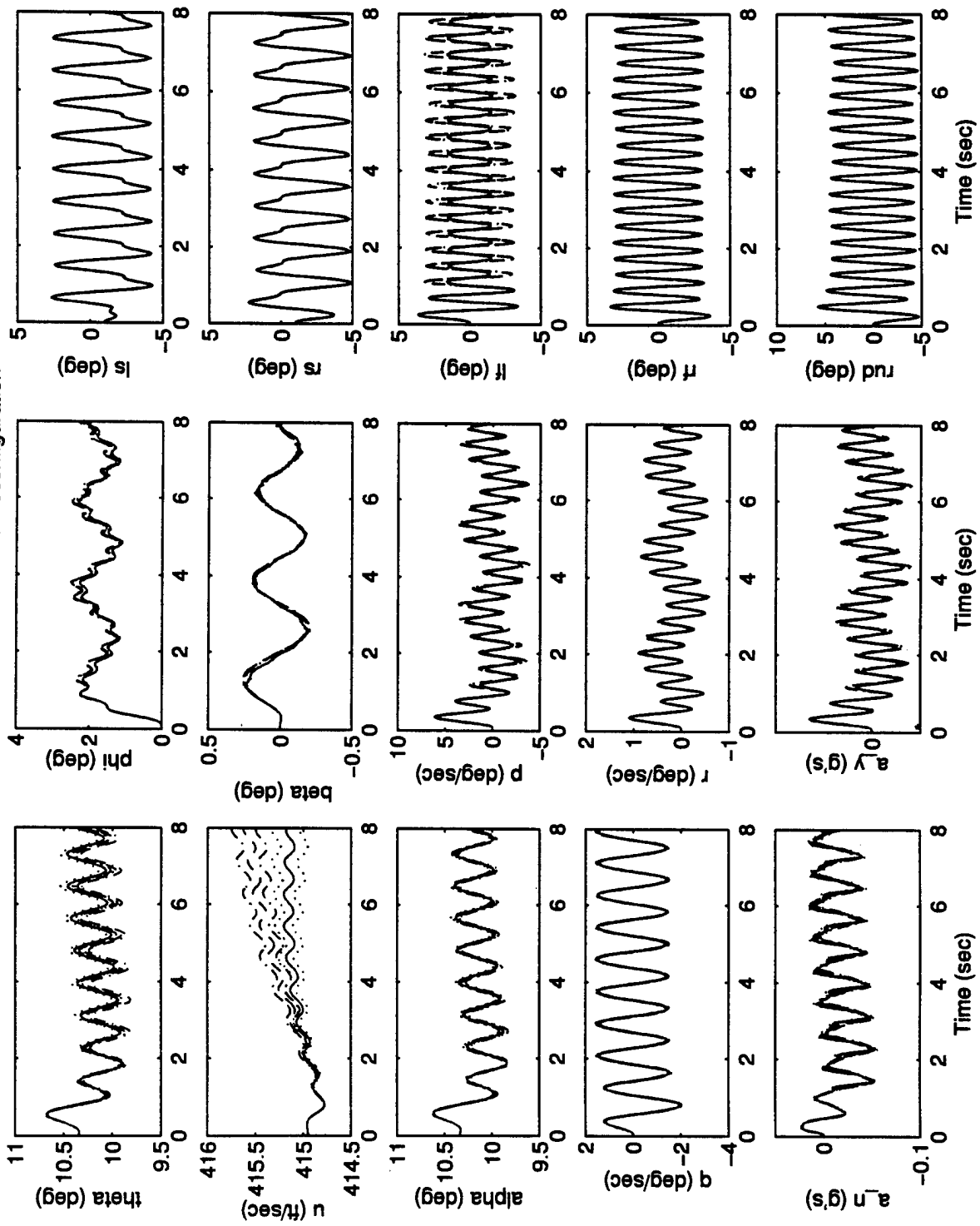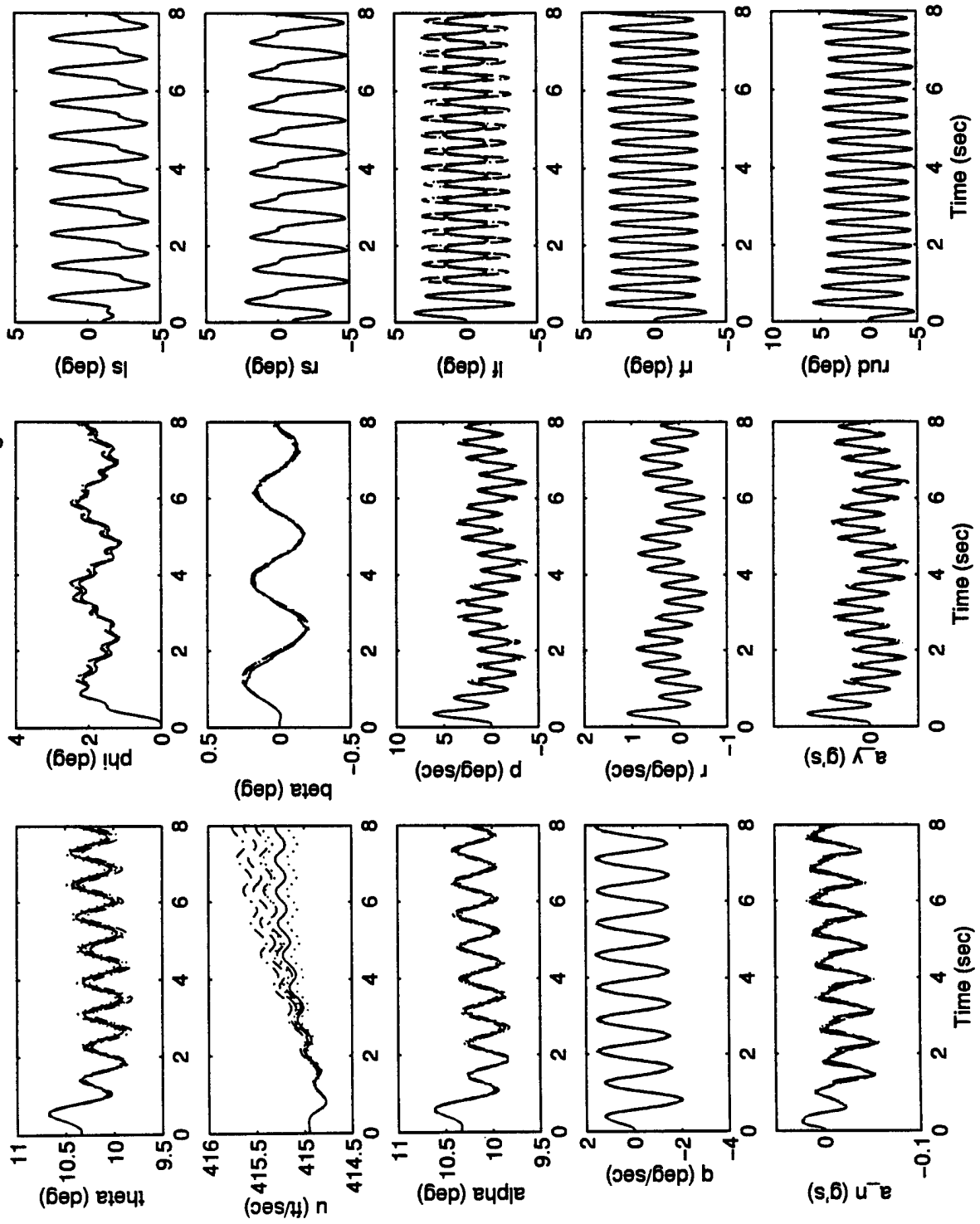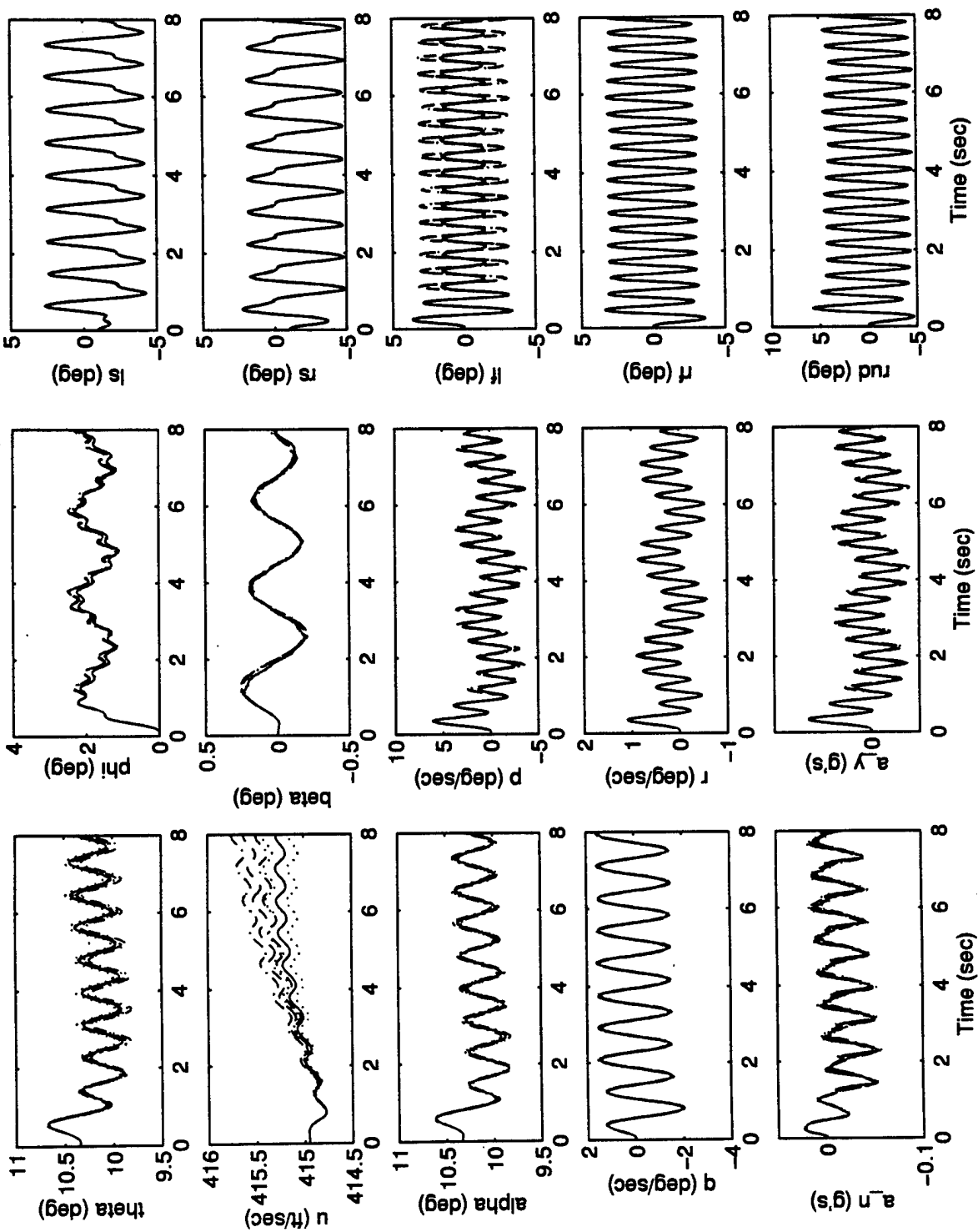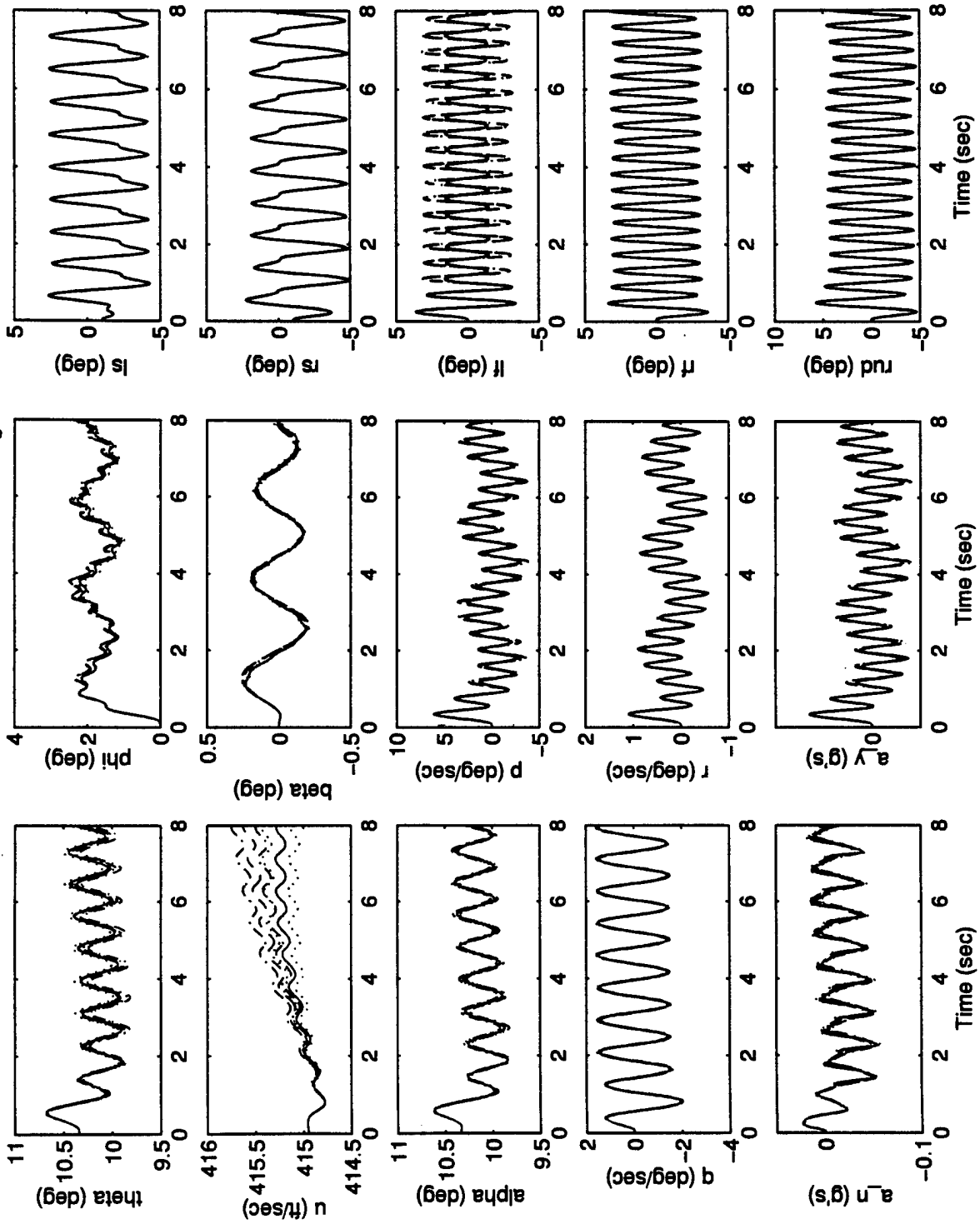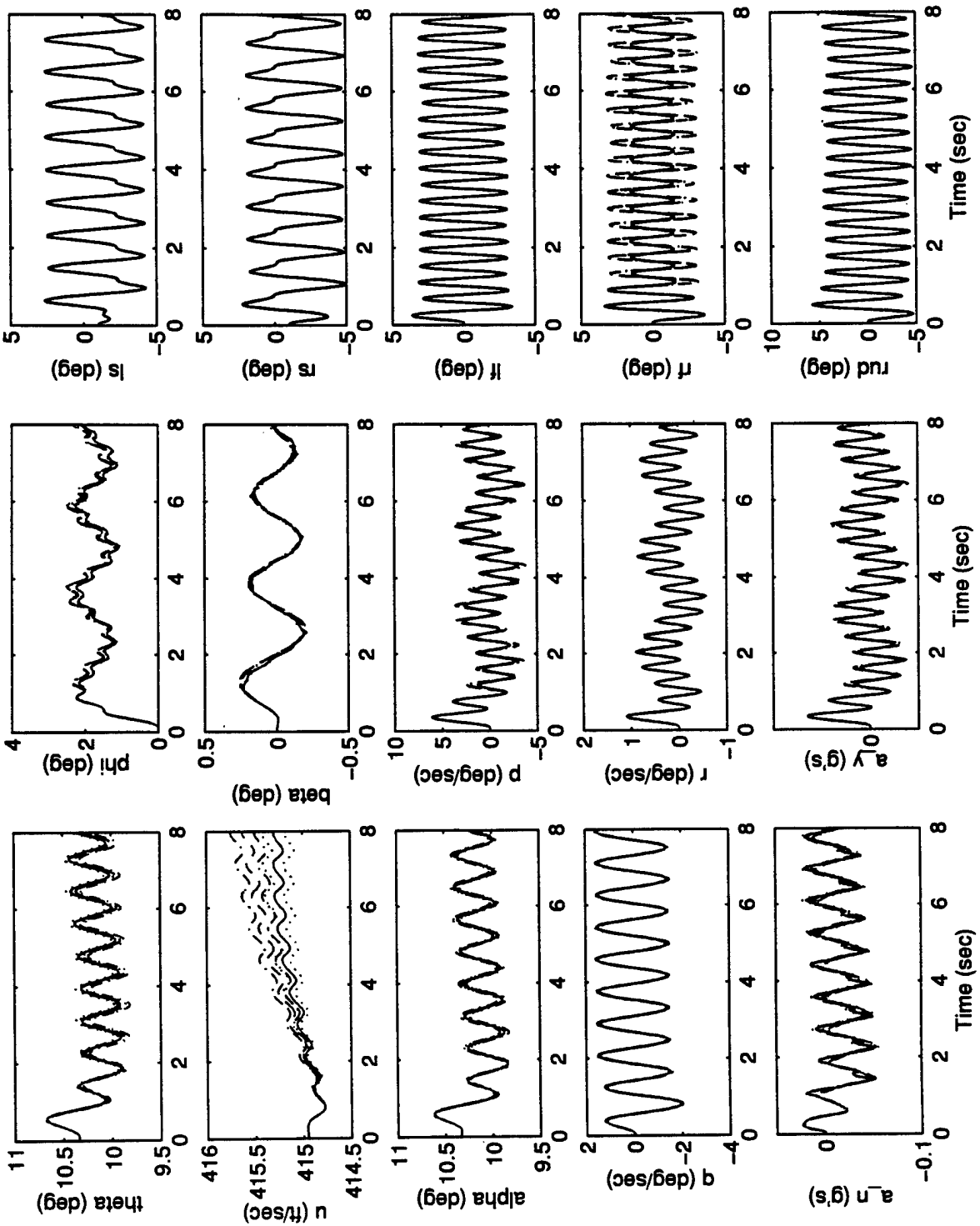dual-failure fail505.09 with reconfiguration

dual-failure fail505.010 with reconfiguration
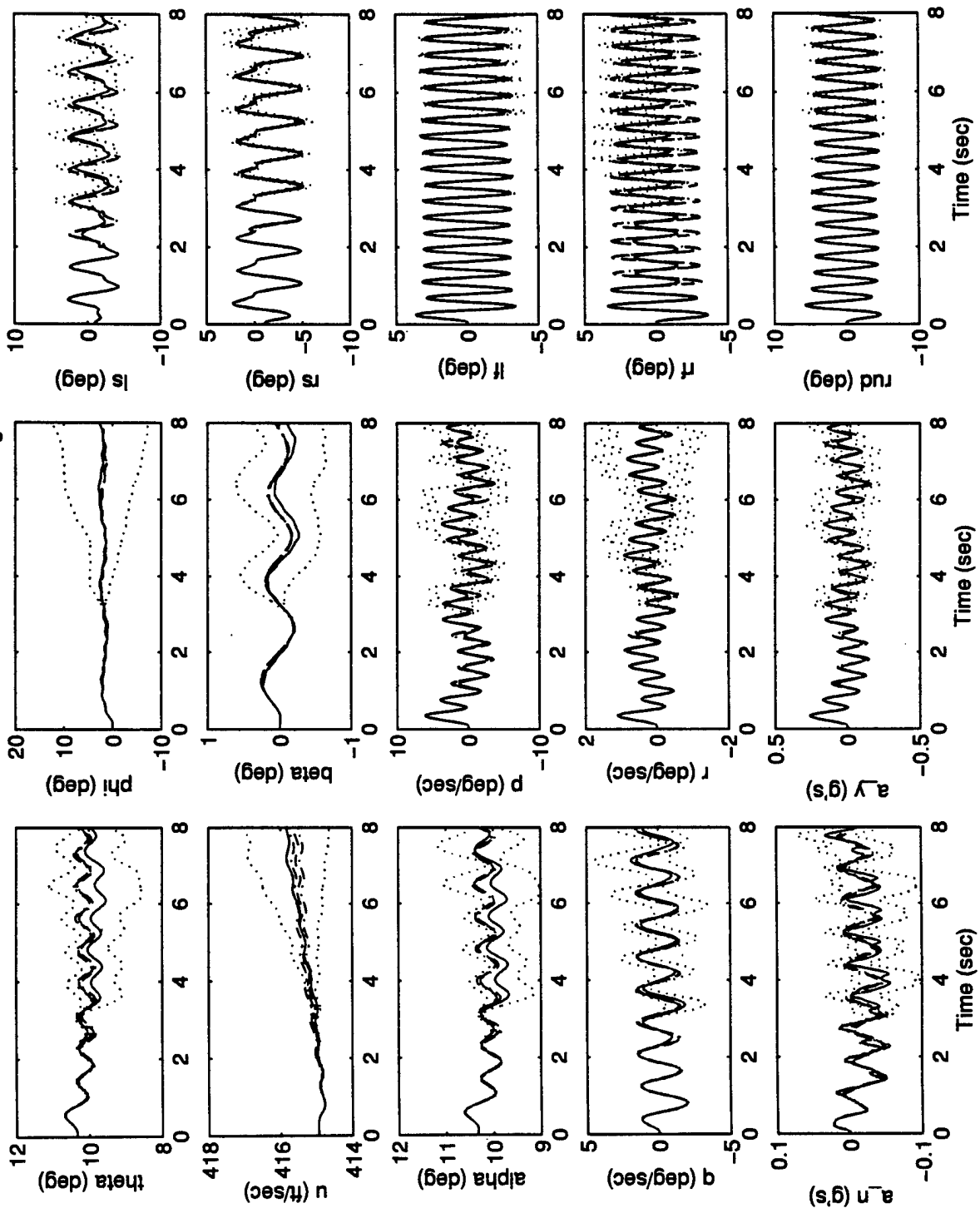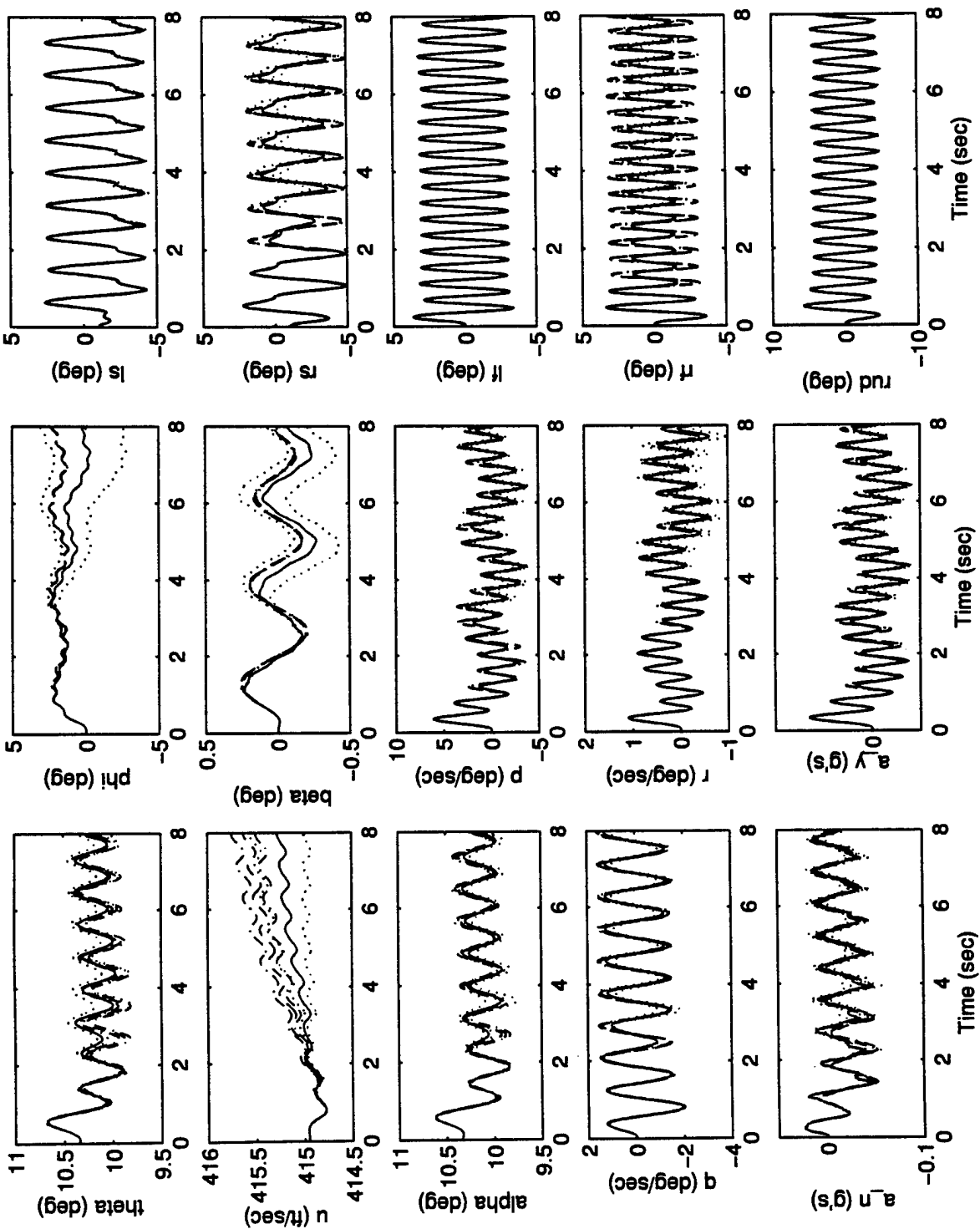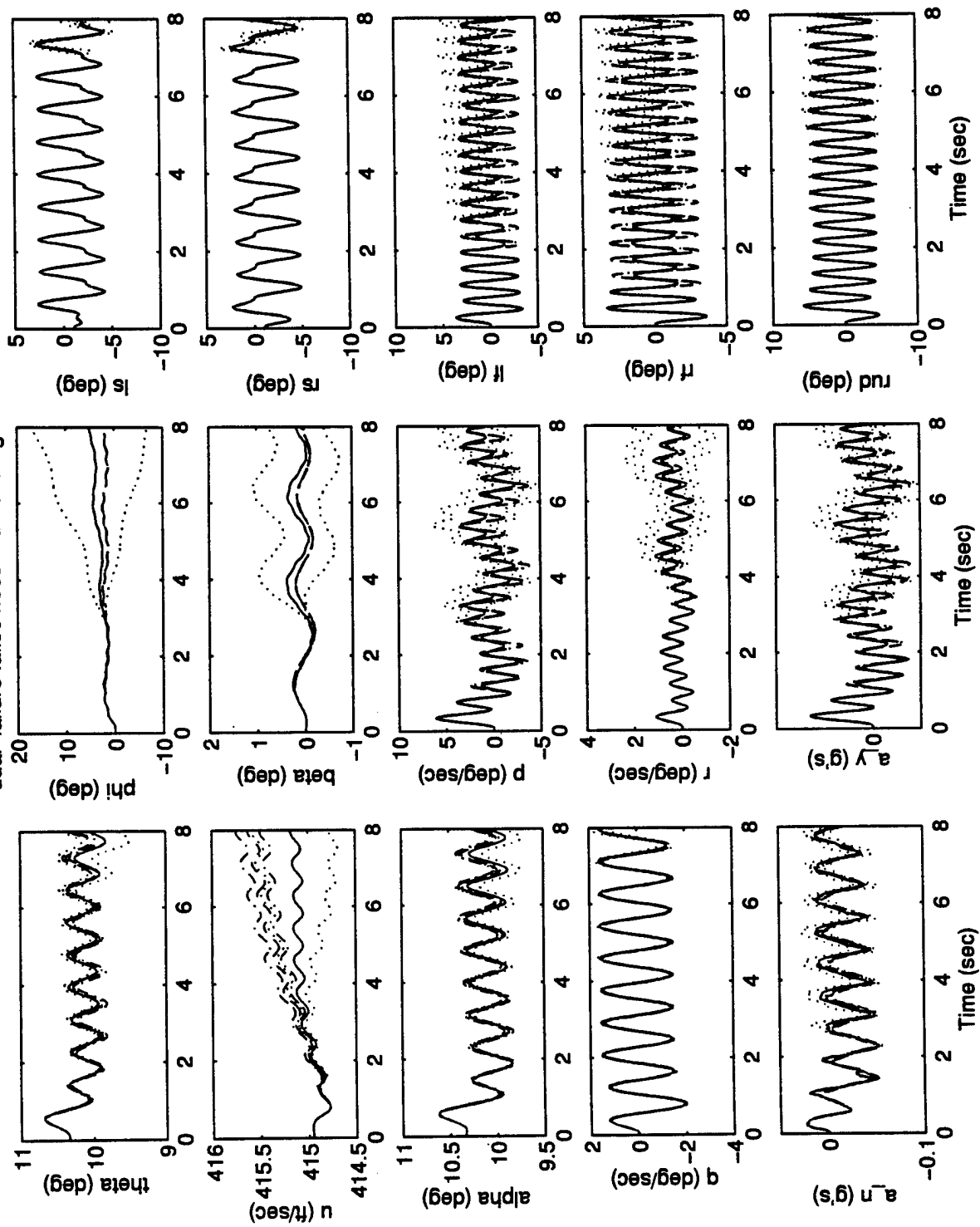
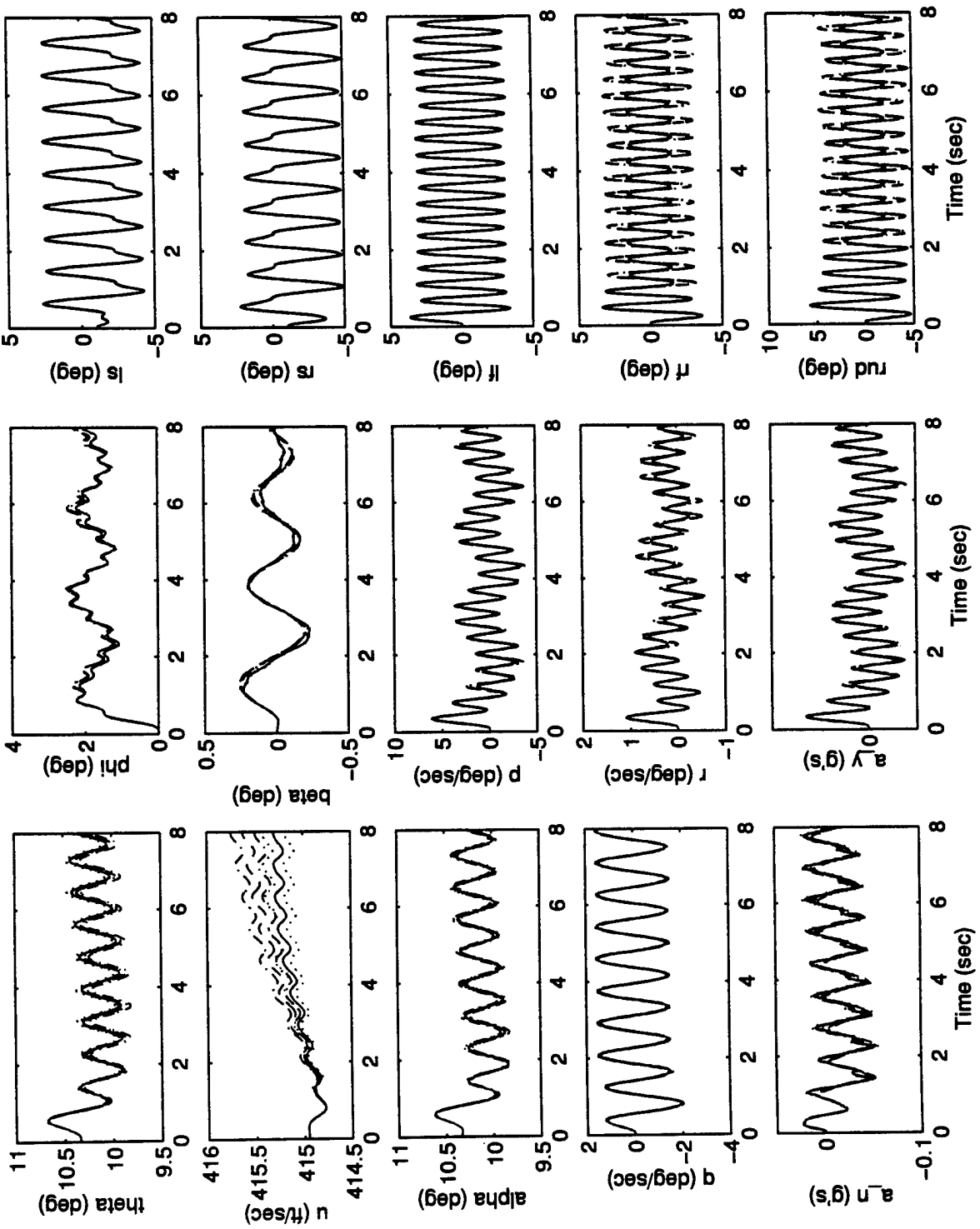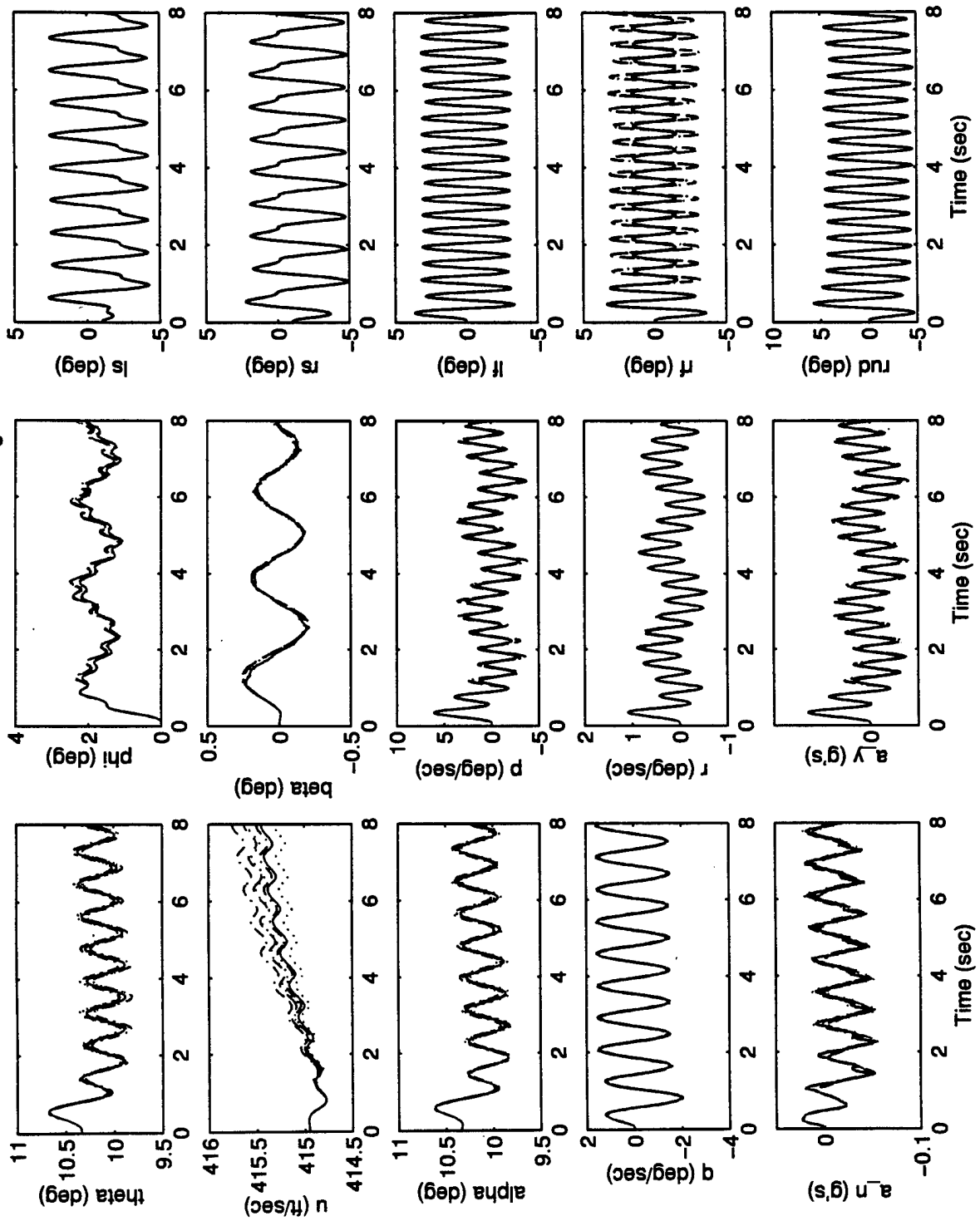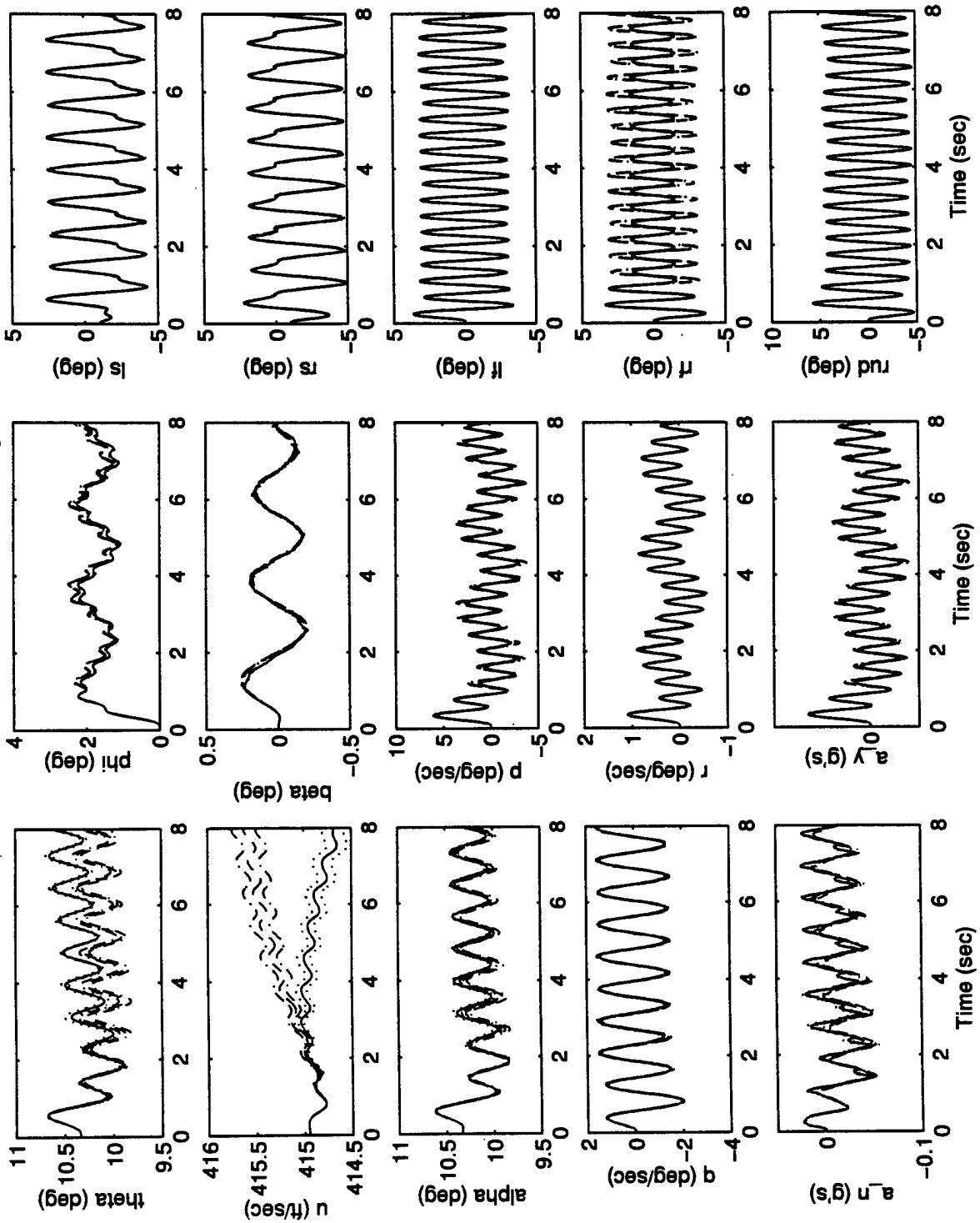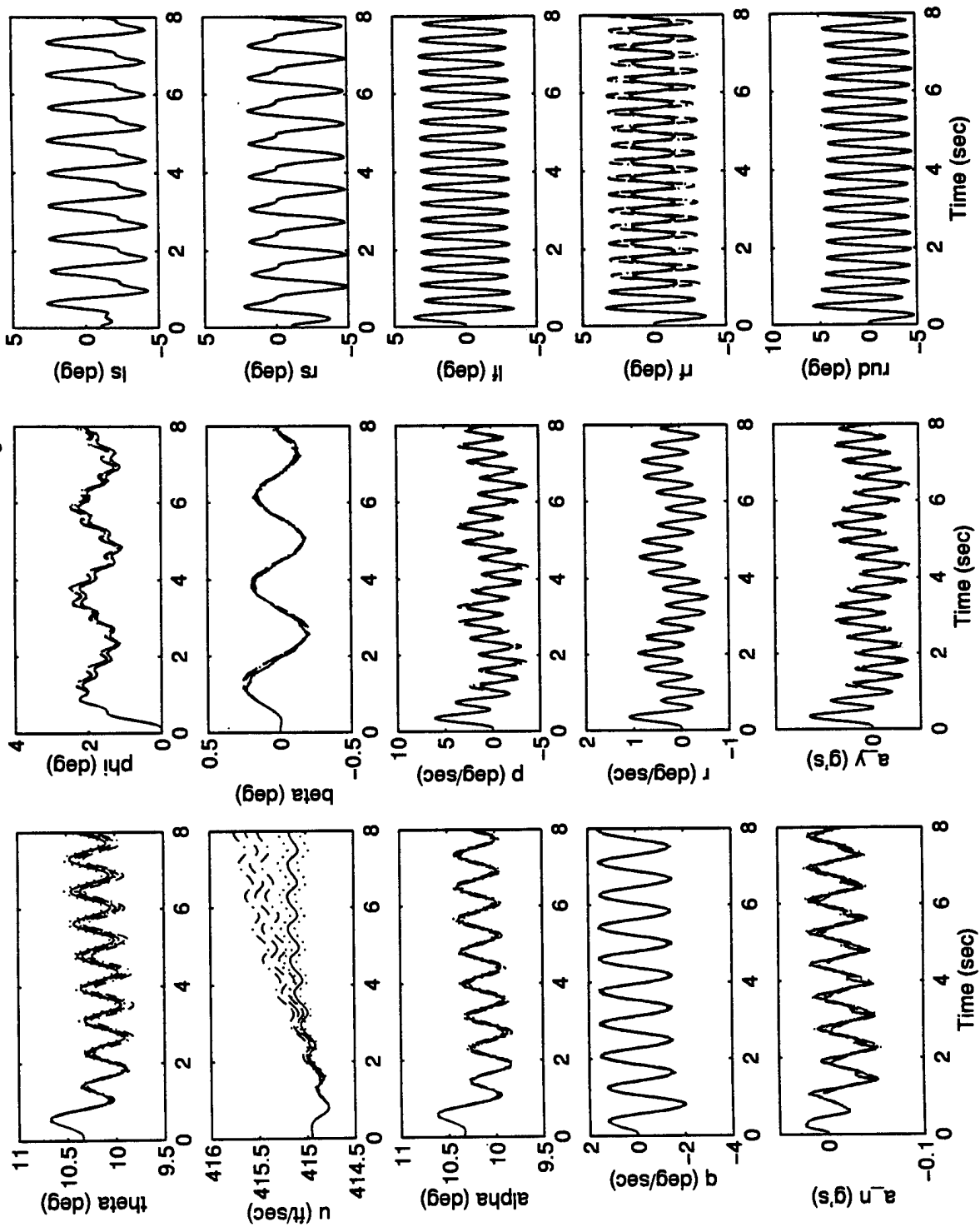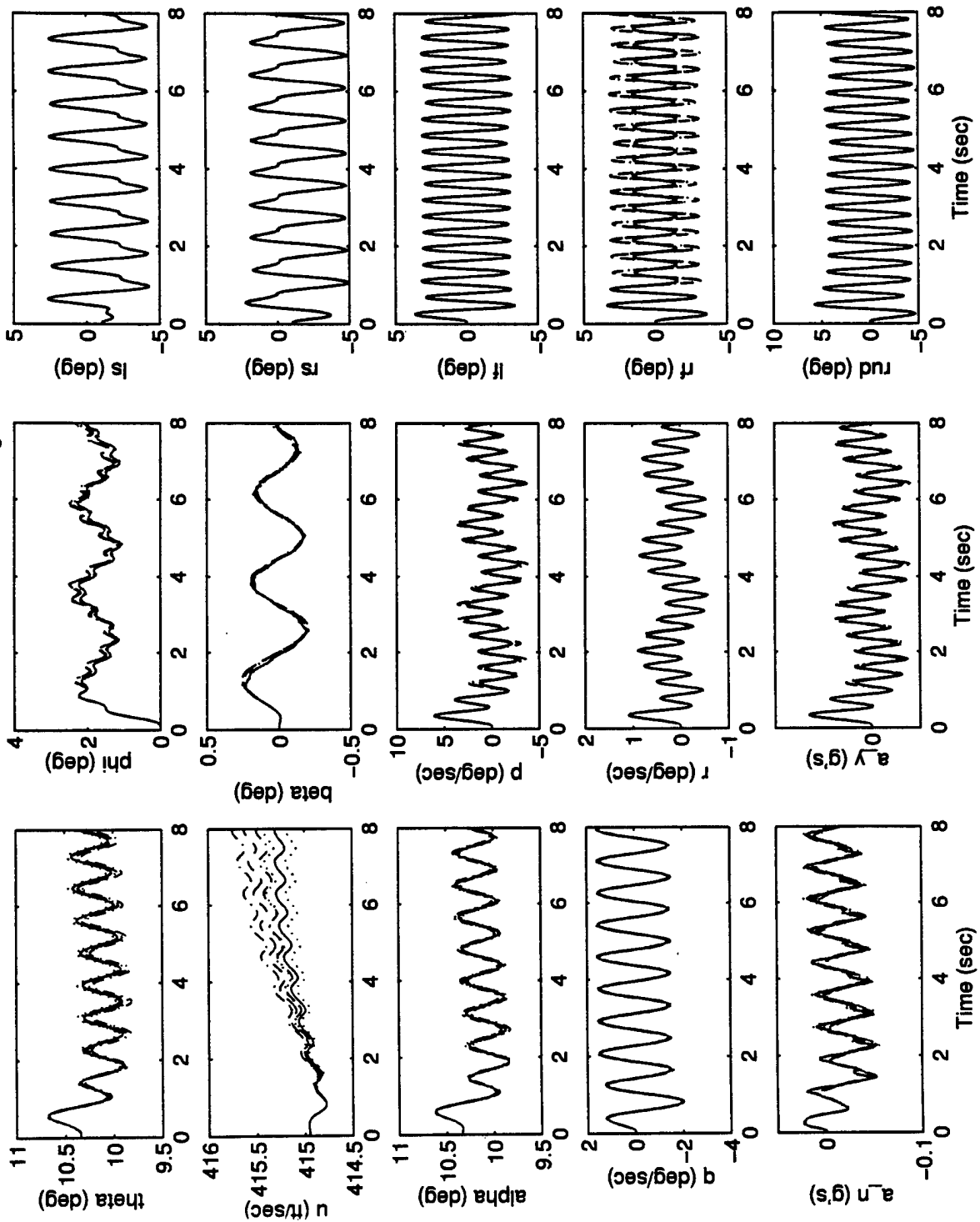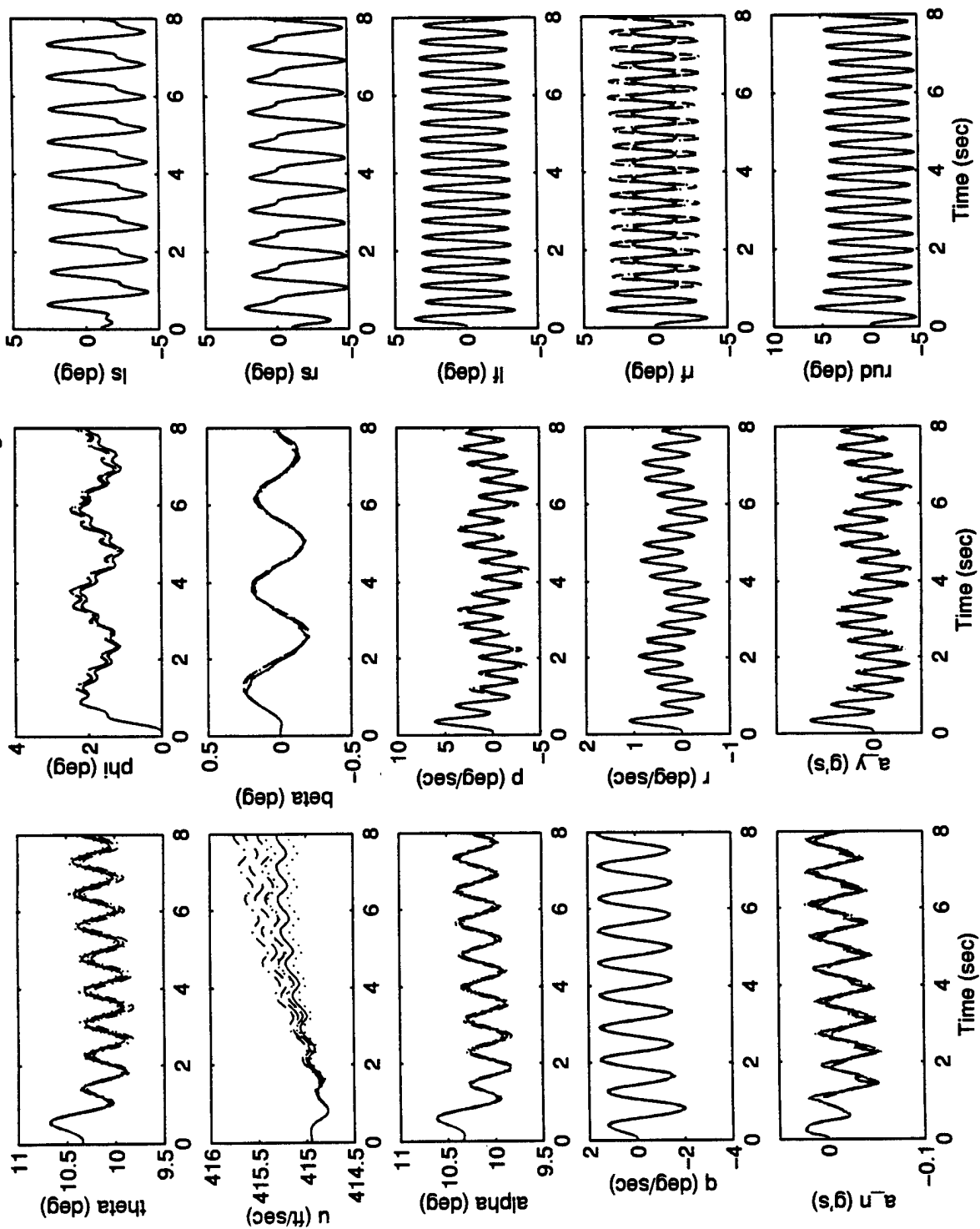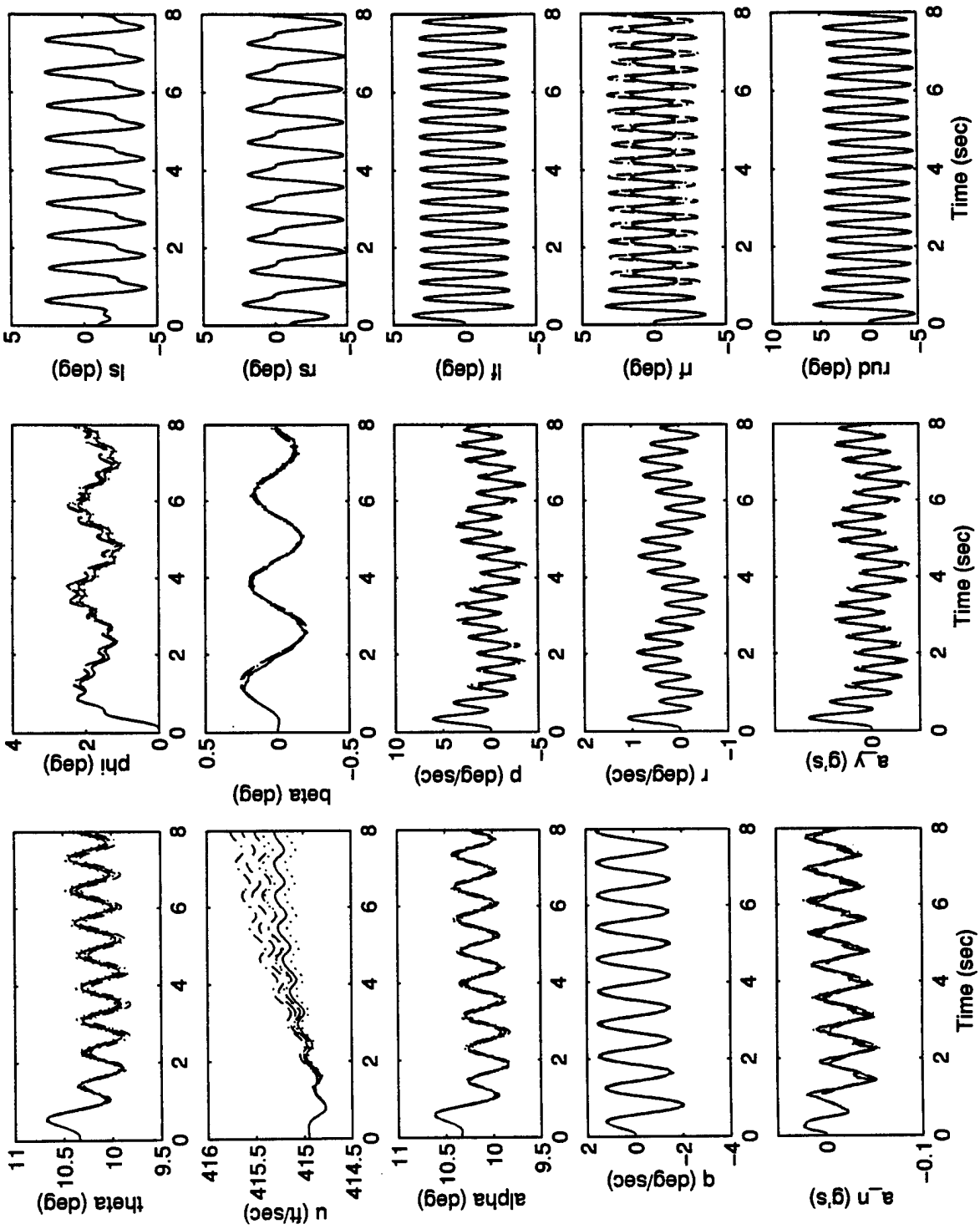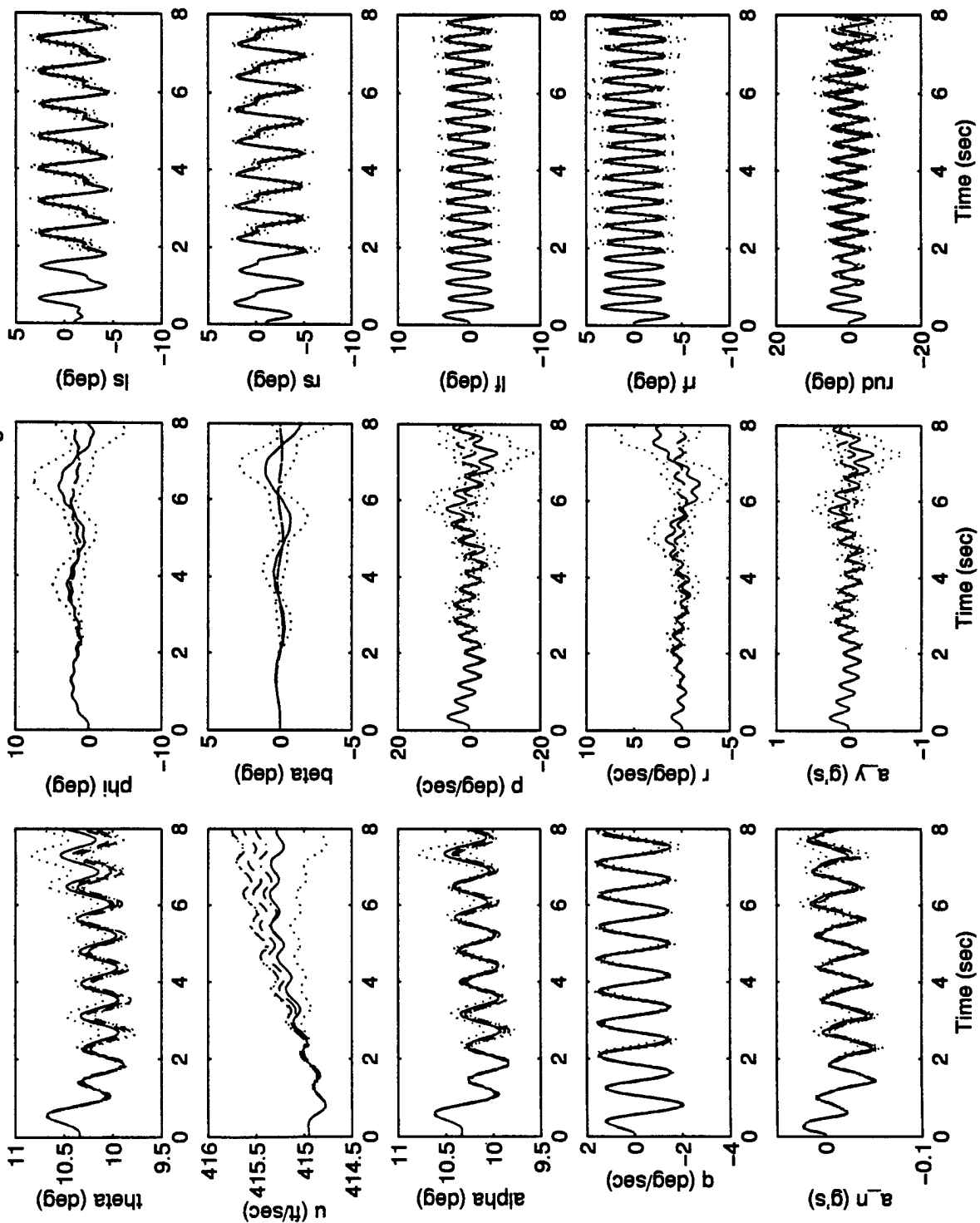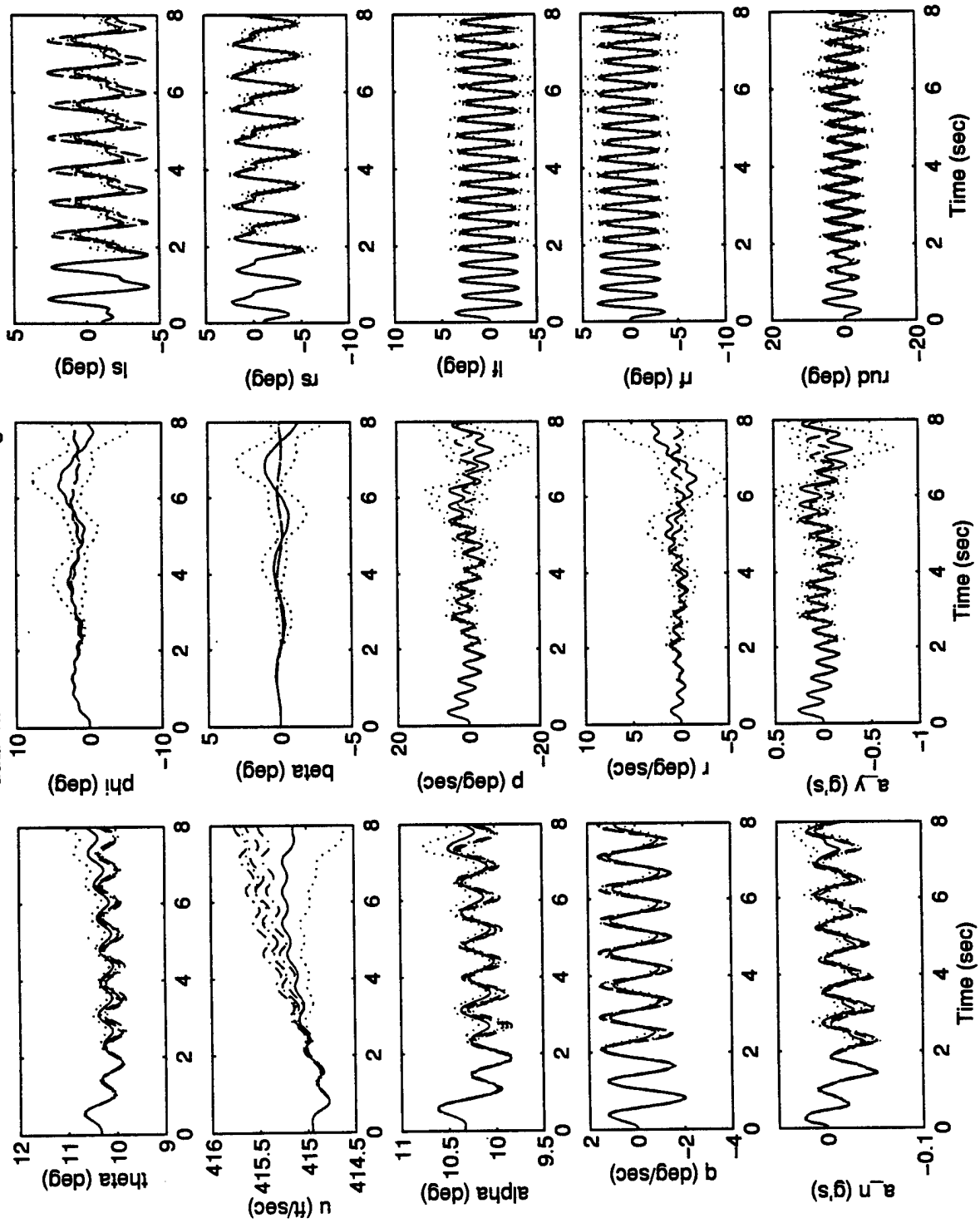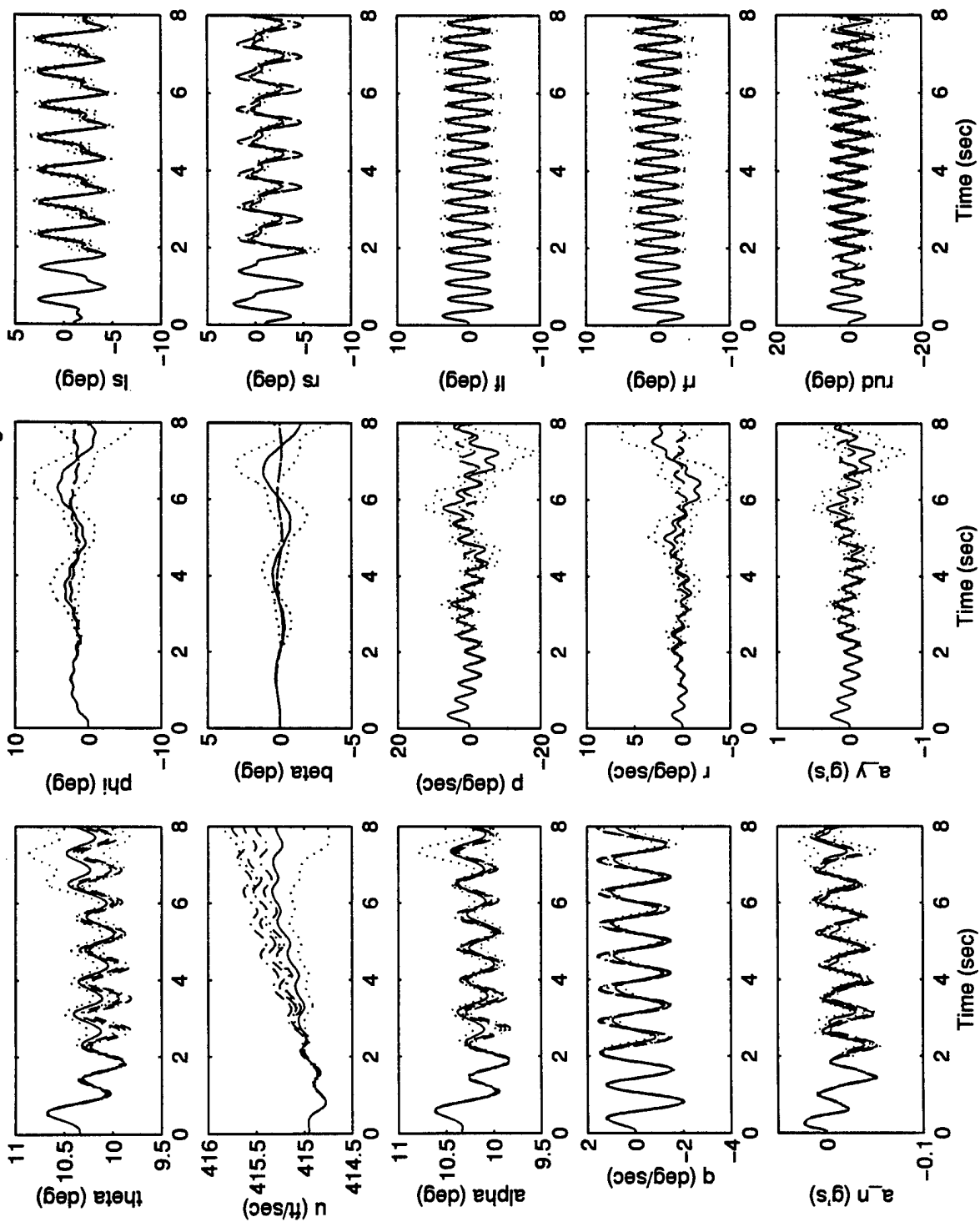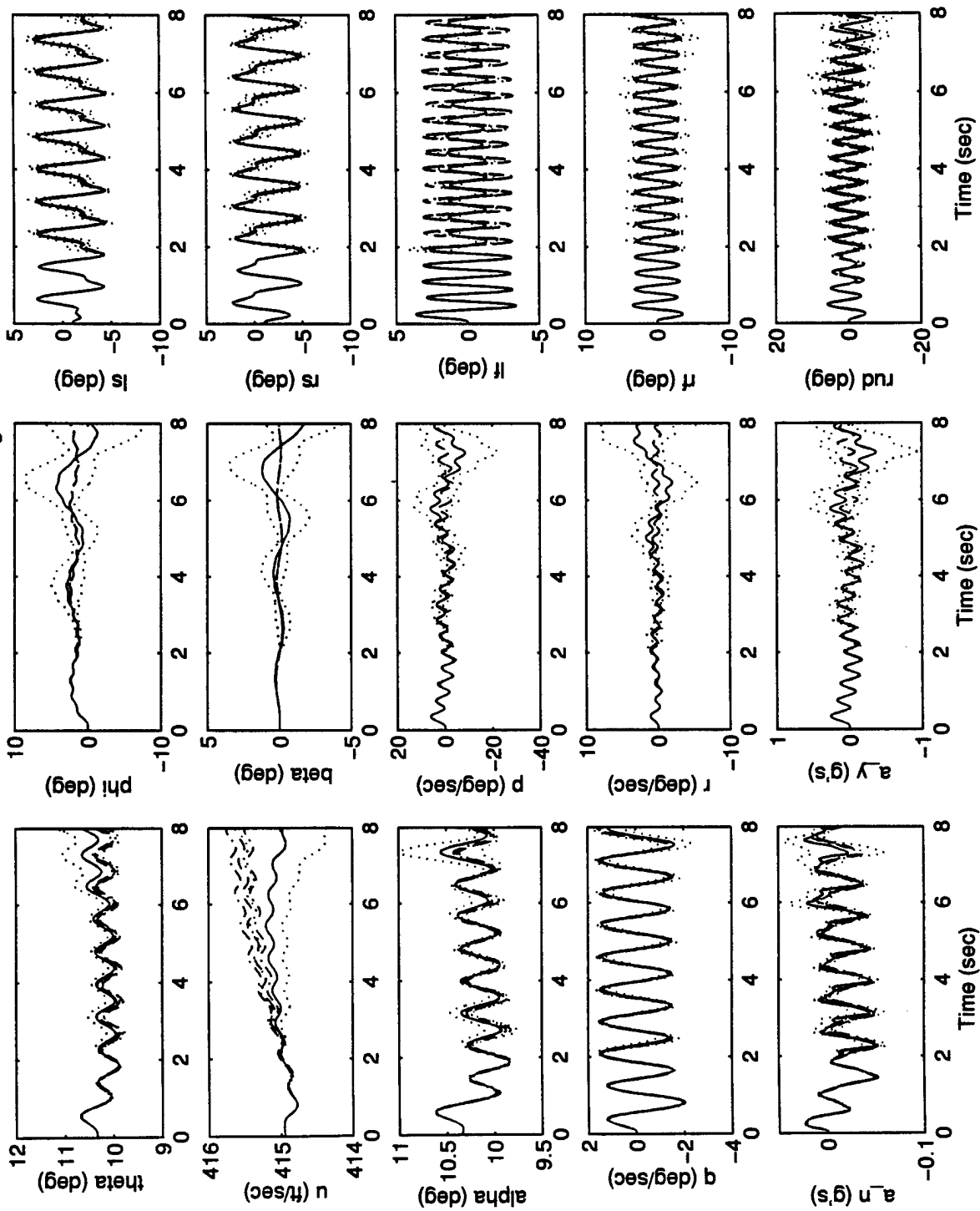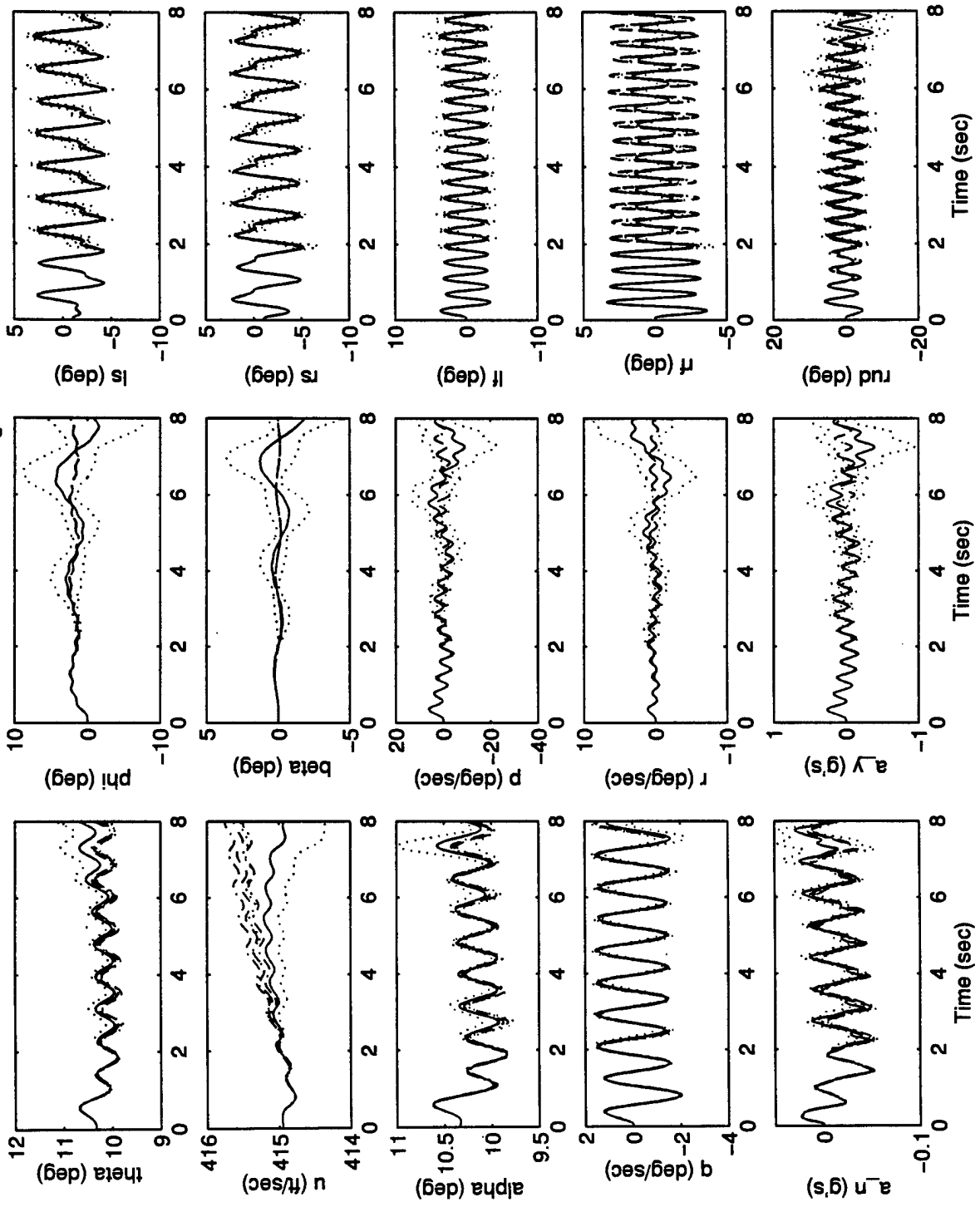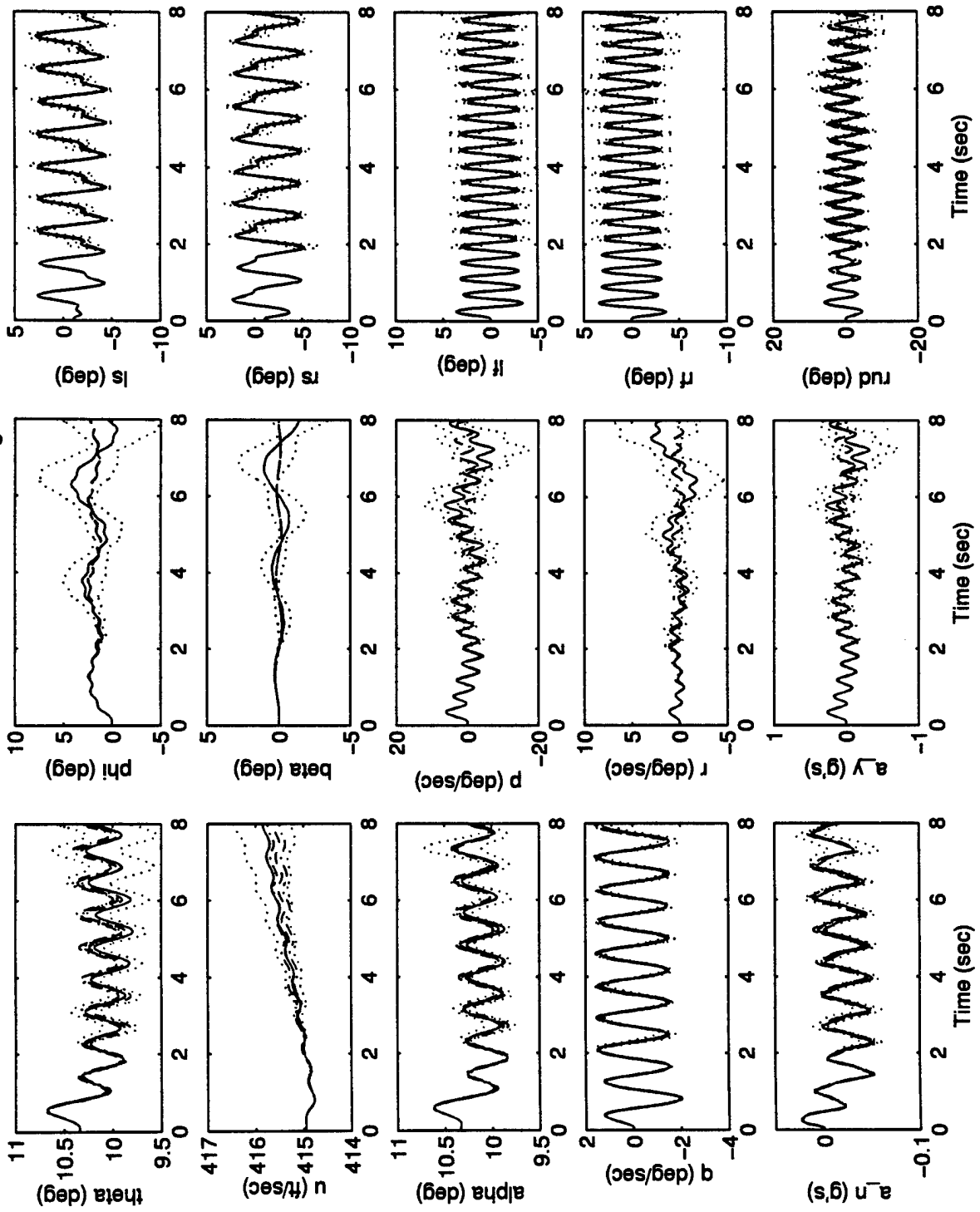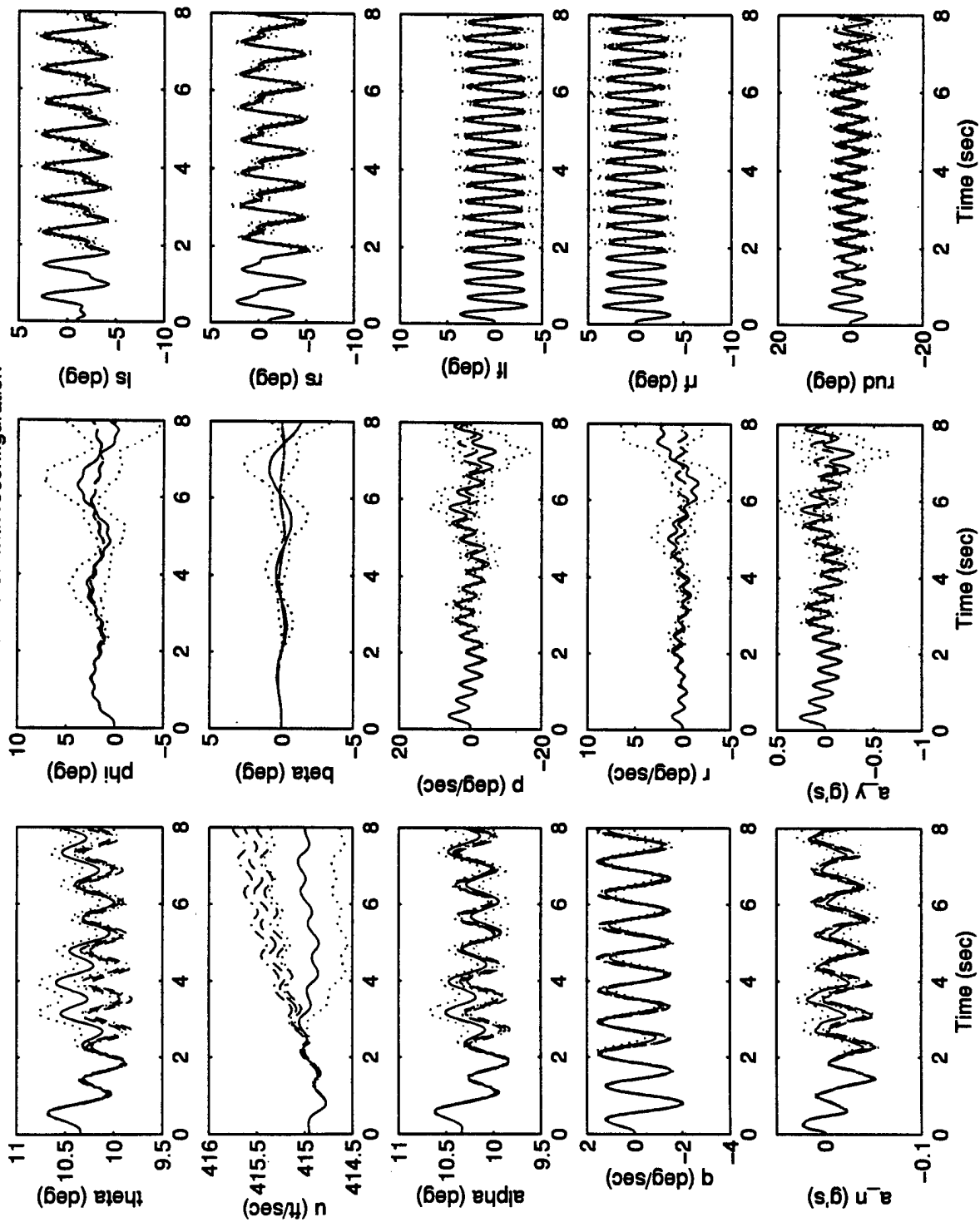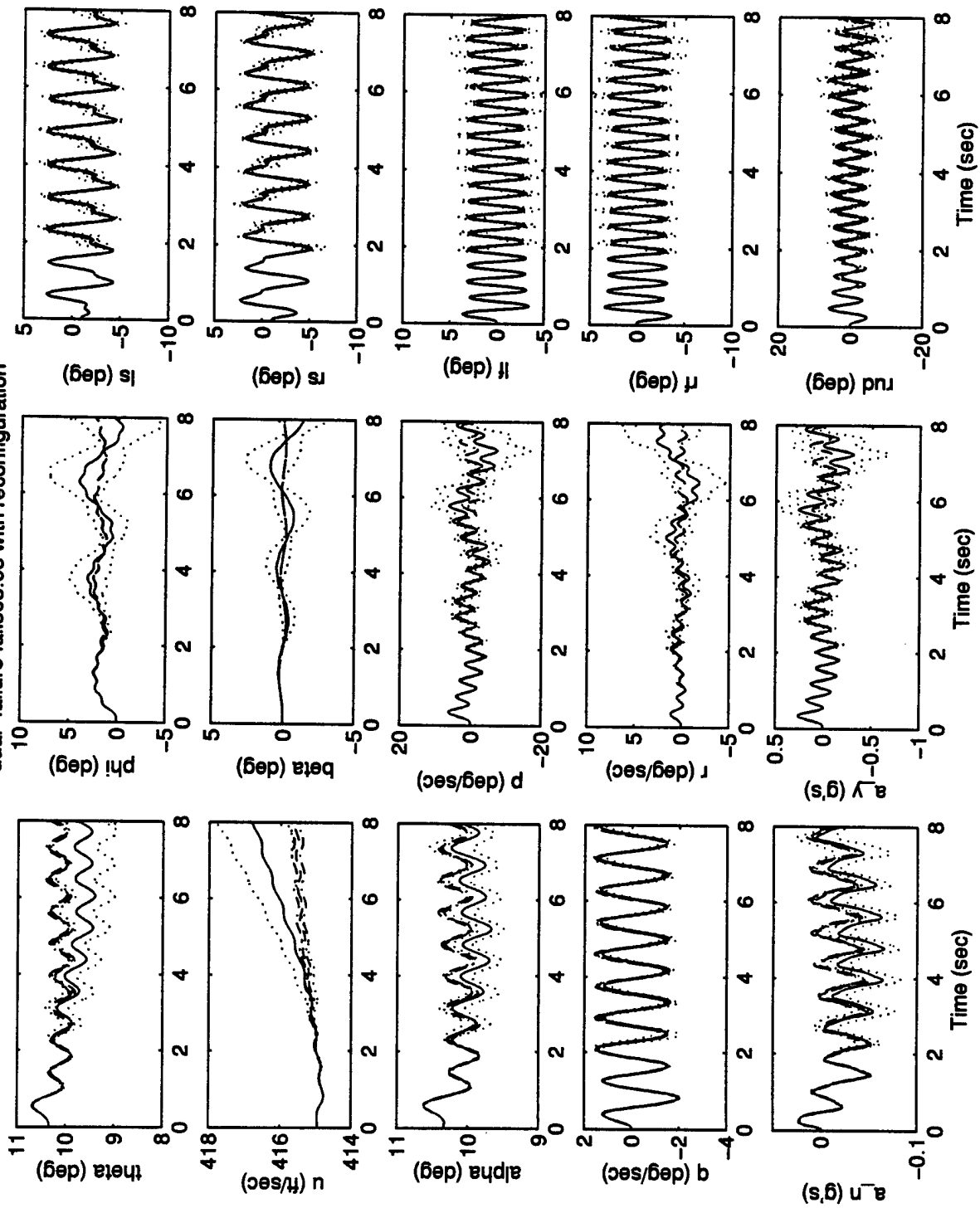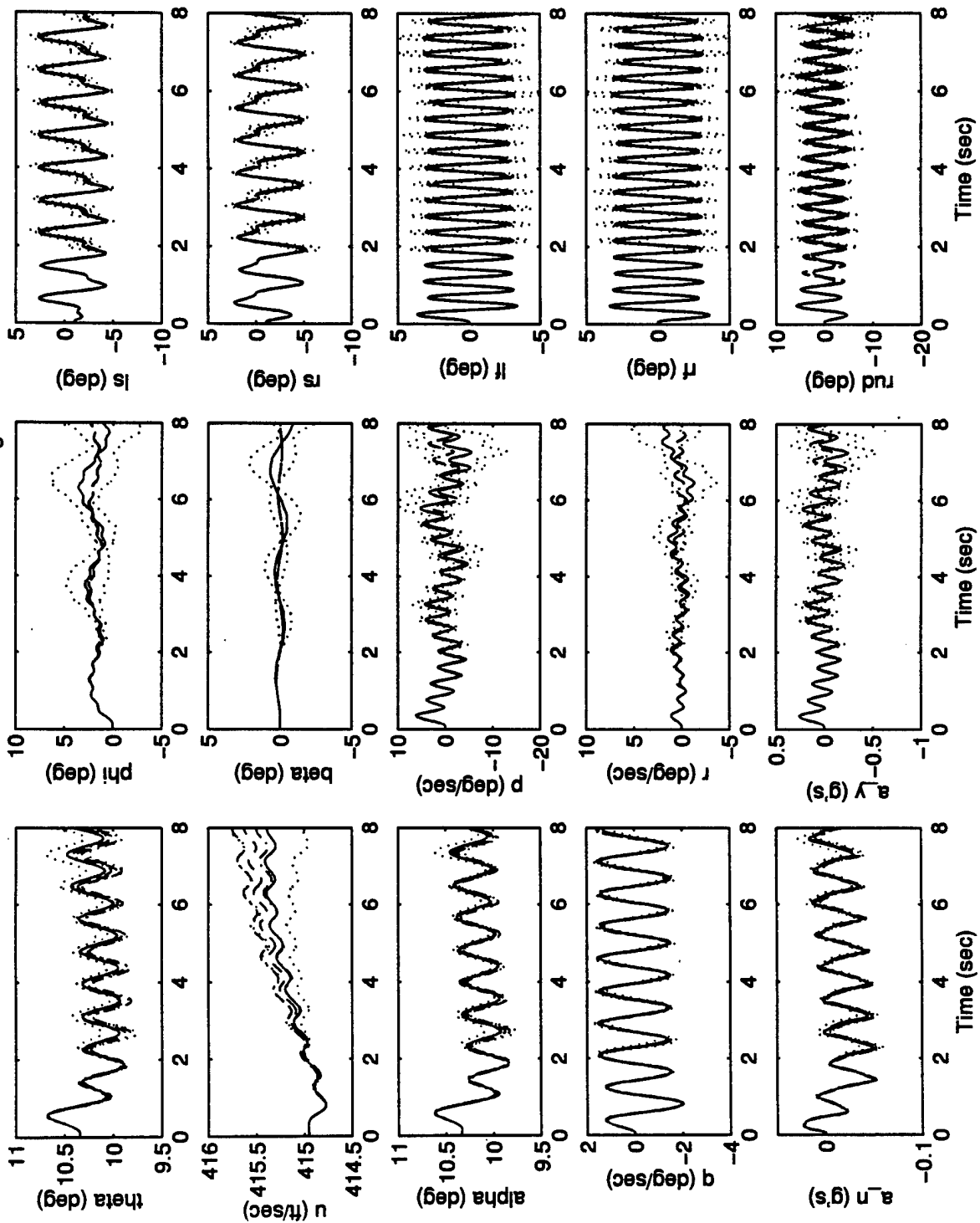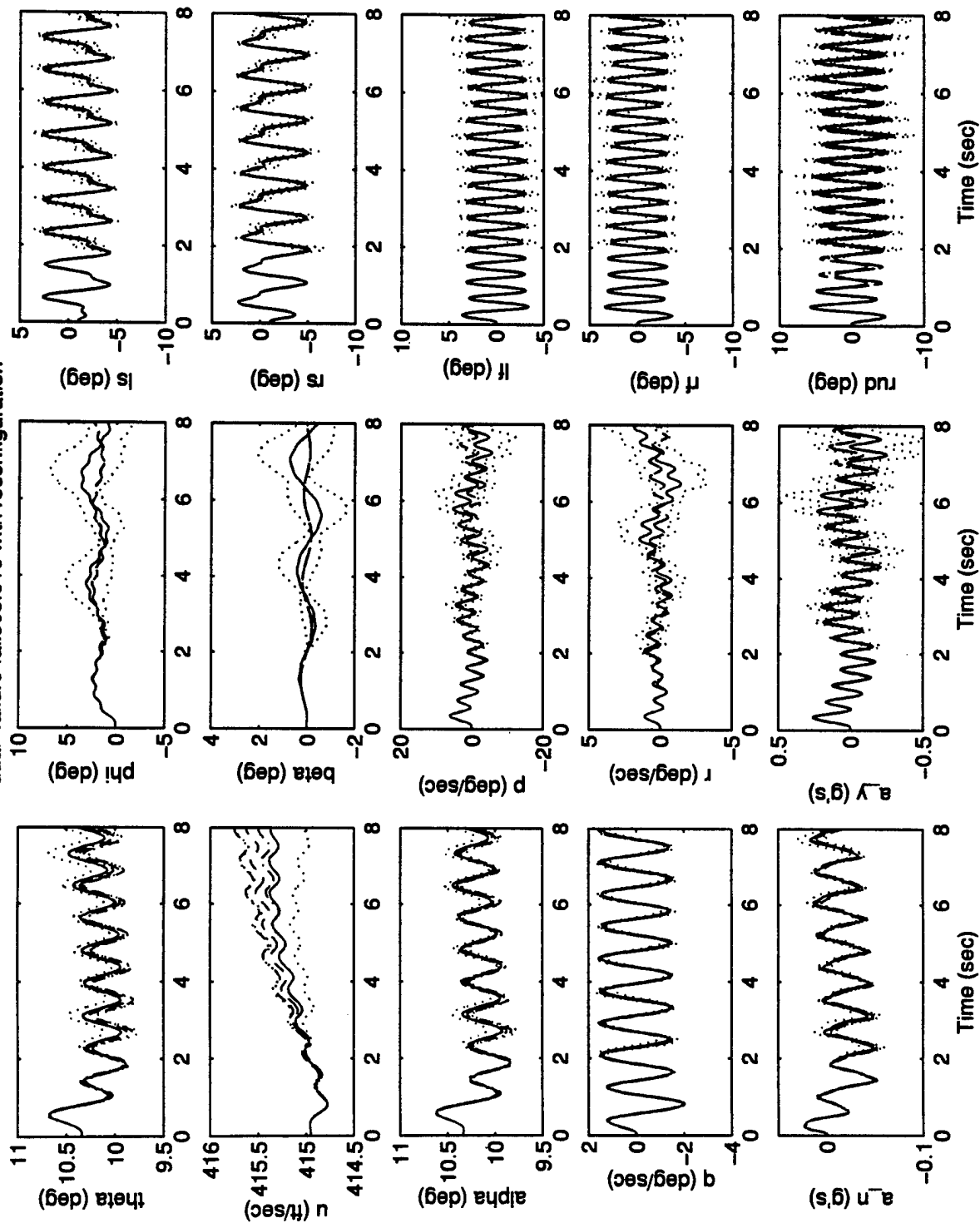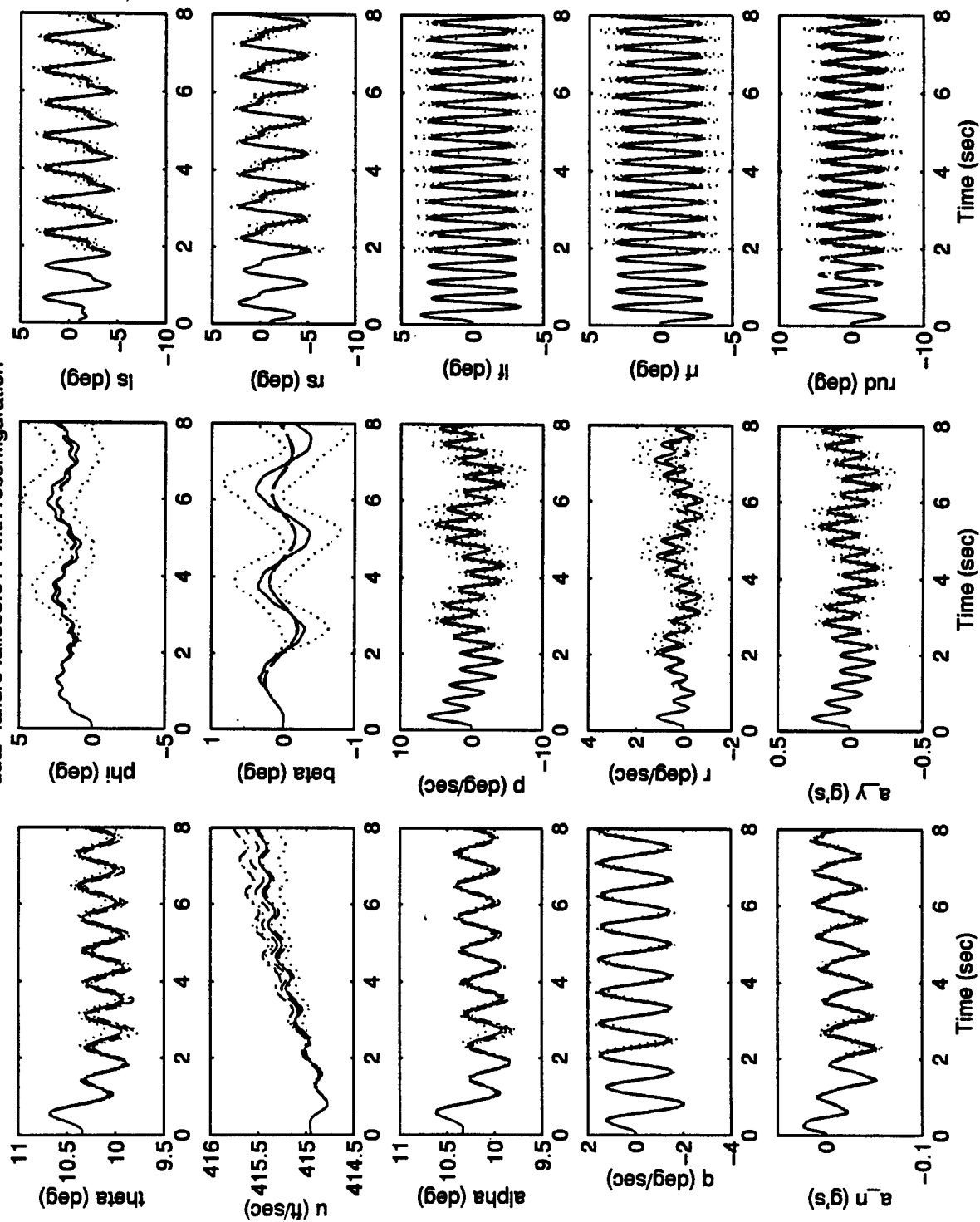dual-failure fail505.011 with reconfiguration

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MULTIPLE MODEL ADAPTIVE ESTIMATION AND CONTROL REDISTRIBUTION PERFORMANCE ON THE VISTA F-16 DURING PARTIAL ACTUATOR IMPAIRMENTS

5. FUNDING NUMBERS

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12a. DISTRIBUTION AVAILABILITY STATEMENT
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12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
Multiple Model Adaptive Estimation with Control Reconfiguration (MMAE/CR) capability to estimate and compensate for partial actuator failures, or "impairments" is investigated using the high-fidelity, nonlinear, six-degree-of-freedom, VISTA F-16 simulation which currently resides on the Simulation Rapid-Prototyping Facility (SRF). After developing a model for inserting partial actuator impairments into the VISTA F-16 truth model, research begins with a battery of single actuator impairment tests. This stage of research explores the capability of the existing MMAE algorithm to estimate single, partial actuator impairments, and helps to define refinements and expansions needed in the MMAE algorithm for the second phase of research: the detection and estimation of dual, total and partial actuator impairments. It is seen from the first stage of research that, while MMAE is able to estimate partial impairments, there are refinements needed, such as "probability smoothing and quantization", to compensate for the quality of MMAE probability data and to provide a better, more stable estimate value to the Control Reconfiguration module. The Kalman filters and the dual, partial failure filter banks necessary for the detection of dual, partial actuator impairments are also defined as a result of the single impairment tests. Fifteen more banks of "partial first-failure" Kalman filters are added to the existing MMAE algorithm, as well as the "bank swapping" logic necessary to transition to them. Once the revised and expanded MMAE/CR algorithm is ready, research begins on dual combinations of total and partial actuator impairments. While results of these tests (for other than total impairments) are not as good as originally hoped or expected, the potential for better performance is evident.

14. SUBJECT TERMS
Multiple Model Adaptive Estimation, MMAE, Kalman Filter, F-16, Control Reconfiguration, Flight Control, Failure Detection, Reconfigurable Control

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